The WELDING JOURNAL

APRIL 1952

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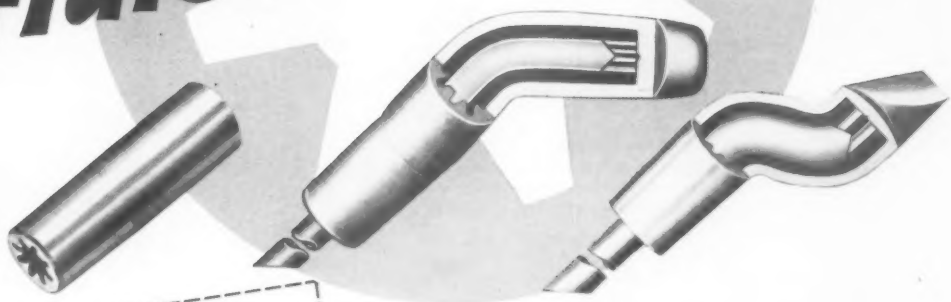

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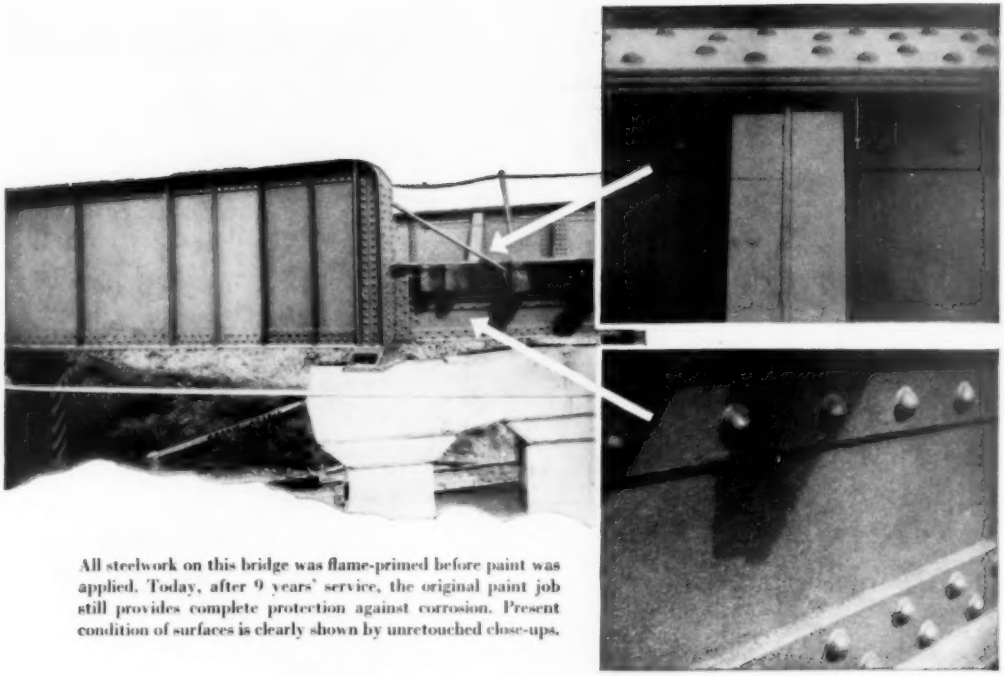

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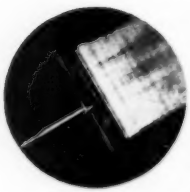

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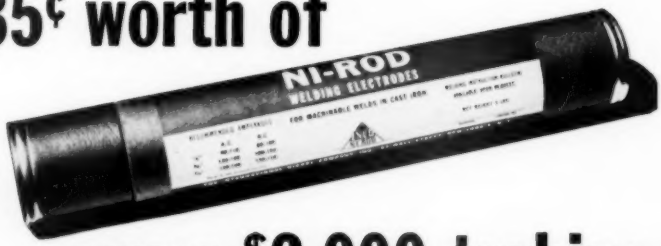

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The WELDING JOURNAL

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The Metallizing Process

A brief historical review of the metallizing process, its field of application, apparatus needed, methods used in preparation of surfaces, the nature of the coatings and some applications

by F. Keller

TWO factors—wear and corrosion—are constantly taking a heavy toll of costly equipment and structures; consequently, many items are scrapped on account of excessive wear and much effort is continually expended to combat corrosion of various types. In these fields, metallizing presents a convenient and practical method for rebuilding worn machine parts and a very effective means of protection against corrosive attack. Although this process has been available for many years, it probably has not been used as extensively as it should have been. The metallizing process should be of considerable interest to industry, both for repair and maintenance as well as for production.

Recognizing the merits and applicability of metallizing and its relation to welding practices, the AMERICAN WELDING SOCIETY formed a Committee on Metallizing in 1944. This committee has been working on Recommended Practices for Metallizing and is sponsoring this group of three papers to make current information available on this subject.

One of the advantages of the metallizing process is that it employs portable equipment. This makes the process adaptable for the rebuilding of worn machine parts and for applying protective metallic coatings to relatively large assemblies and structures. Furthermore, coatings of various metals and alloys in controlled thicknesses up to $^1/_2$in. or greater can be applied readily. This is accomplished without any appreciable distortion of the basic structure because the parts do not reach a high temperature during spraying. Any metals that are available in wire form can be sprayed. These include low-carbon and high-carbon steel, stainless steel, aluminum, zinc, lead, tin, cooper, brass, bronze, nichrome, nickel, monel, tantalum, molybdenum, silver and gold. Some of these metals are used for repairing worn parts; others are applied for protective or decorative purposes.

The original idea of applying metallic coatings by spraying was conceived by M. U. Schoop of Zurich, Switzerland, in 1910. Although metallic powders had been made previously by atomizing a stream of molten metal by means of a strong air blast, Schoop was the first to interpose an object in the path of the atomized particles to obtain a continuous metallic coating. In this work, a crucible of molten metal was employed from which a small stream of the metal was atomized through a nozzle by a jet of compressed air. This process, however, was not found convenient or practical and lead to the development a few years later of a metallizing gun employing wire. By this development, metallizing became a much more practical process.

The metallizing process was introduced in this country in 1920 with the importation of the Schoop wire-type gun. From then until about 1932, much of the development work was done in Europe and the applications of the process were more widespread than in this country. Although suitable equipment and methods were available to potential users in this country, the licensing arrangements under existing patents did not encourage wide usage. After the basic patents expired, many further developments were made in equipment and procedures and the applications for metallizing increased markedly.

EQUIPMENT FOR METALLIZING

The most important item of equipment needed for metallizing work is a metallizing gun. Such a gun is

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Paper was presented before the Thirty-Second Annual Meeting, AWS, Detroit, Mich., week of Oct. 15, 1951

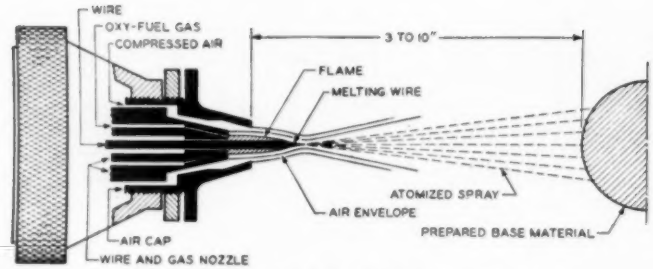

Fig. 1 Shows principles of operation of a metallizing gun

an ingenious device for feeding, melting and atomizing wire of various metals and spraying the atomized particles at high velocity onto the surface being coated. The general principles of a typical metallizing gun are illustrated by Fig. 1. Guns of various sizes using wire from about 0.090 to 0.188-in. in diameter are available for different types of work. Those used for rebuilding machine elements are capable of spraying from about 5 to 20 lb. of steel wire per hour. Other guns designed especially for applying coatings for corrosion protection are capable of spraying about 17 lb. of aluminum or about 60 lb. of zinc per hour. Other items of supplementary equipment for a metallizing unit comprise an air compressor, an air control unit including filter and regulator, tanks of oxygen and acetylene or other fuel gas, a gas control unit with suitable pressure regulators, a gas flow meter, and a wire control unit for handling coils of the metallizing wire. Where protective coatings are to be applied, suitable equipment for sand or grit blasting is necessary.

PREPARATION FOR METALLIZING

Since the bonding of a sprayed metal coating to the basis metal is chiefly mechanical in nature, it is necessary to prepare the surface to be coated by roughening it by some mechanical means or other suitable method to provide initial anchorage for the sprayed particles and to make sure the surface is clean and dry. A number of methods are available for suitably preparing various surfaces prior to spraying. The selection of the best method for a particular application, however, is dependent on the type, size and shape of the object, the kind and thickness of the sprayed coating, the degree of adhesion necessary and the service requirements.

For repairing or reclaiming worn machine elements, several different methods of preparation may be employed. First, the part should be undercut to allow sufficient space for the sprayed metal deposit (Fig. 2). Then the surface may be prepared by one of the following methods: (1) Rough threading, (2) grooving and roughening, (3) grit blasting, (4) electric bonding and (5) metallic spray bonding. Rough threading is one of the simplest methods and is useful in making quick repairs. It should not be used for severe conditions or for heavy deposits. It consists of cutting an ordinary Vee-thread with the lathe tool set to cut a torn or broken thread. Ordinarily, about 24 threads per inch are employed. An example of rough threading is shown by Fig. 3.

The grooving and roughening method is used for machine element work where the strongest bonding is

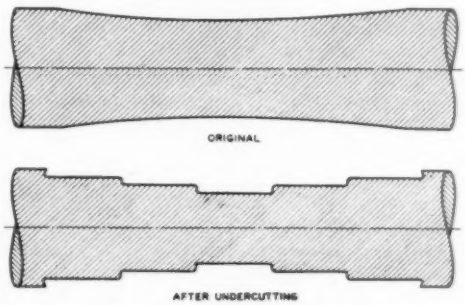

Fig. 2 Shows how a worn shaft is turned down to provide space for depositing sprayed metal

required. It consists in cutting a series of spiral or annular grooves in the undercut section and then spreading and roughening the tops of the grooves by means of a special roughening tool.

Blasting with sand, Joplin grit or crushed steel grit is generally employed for preparing surfaces for receiving corrosion resistant coatings of aluminum or zinc. It is seldom used for machine elements, although it may be employed in conjunction with threading or grooving. Grit blasting is usually done on machine elements with G-16 to G-25 clean, sharp crushed steel grit or similar size aluminum oxide by a pressure blasting machine. The essential feature of a grit-blasted surface is that it should have sufficient "tooth" to help the sprayed particles to form a good

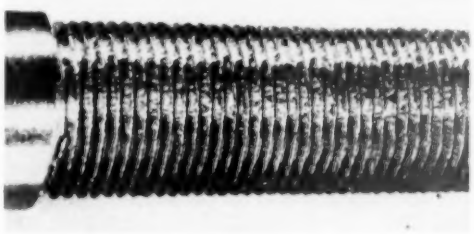

Fig. 3 Example of rough-threading method of surface preparation

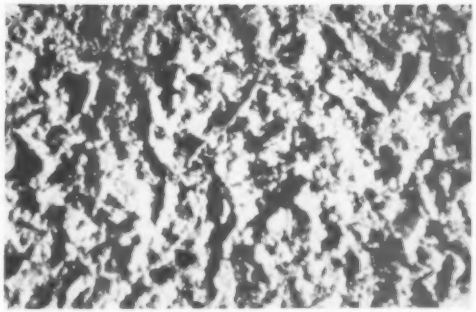

Fig. 4 Appearance of surface of steel sheet after grit blasting with crushed steel grit. Mag. 20 ×

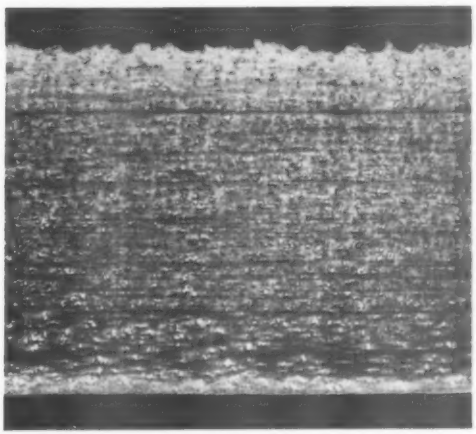

Fig. 5 Cross section of above steel sheet showing type and extent of roughening required to obtain bonding of the sprayed metal layer. Mag. 20 ×

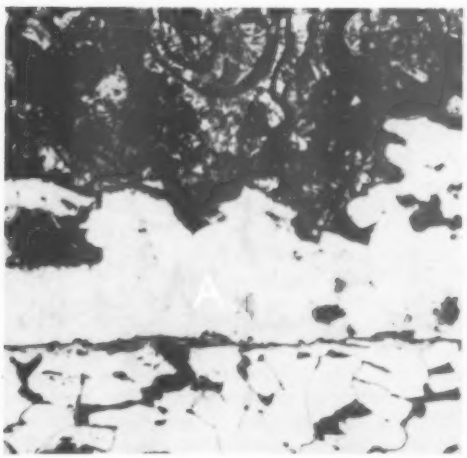

Fig. 6 Shows boundary layer "A" produced by electric bonding method. Mag. 1000 ×

mechanical bond with the roughened surface. The appearance of a suitable grit-blasted steel item in both surface and cross section is shown by Figs. 4 and 5.

Electric bonding is recommended for preparing surfaces that are too hard to roughen by blasting or the other mechanical methods. In this method, a nickel electrode is employed to deposit and fuse small irregularly shaped particles of the electrode to the surface, thus producing a roughened surface to receive the sprayed deposit. The character of the roughening obtained by this method is shown by Fig. 6.

The metallic spray bonding method consists in spraying a thin layer of a molybdenum alloy directly onto a clean surface which need not be roughened. This is one of the newer methods of bonding which provides a high strength bond and which can be used for most machine element work especially where corrosion may be a factor. This method is adaptable for preparing either soft or hardened steel surfaces. It can also be used in connection with applying metallized coatings of aluminum or zinc, but should not be used for copper or copper alloys. The appearance of the bond obtained by this method is illustrated by Fig. 7.

NATURE OF METALLIZED COATINGS

Metallized coatings have rather unique structures and properties because they are formed layer by layer of thin lamellae when the atomized globules of the sprayed metal strike the surface being coated at high speed and with considerable impact. Initially, each particle is essentially a tiny casting which has solidified very rapidly and acquired a very thin oxide film during its rapid transit from the gun nozzle to the surface. On impact, the particles are instantly deformed into thin platelets or flakes which conform to the surface contour and bond to the prepared surface by mechanical interlocking with surface irregu-

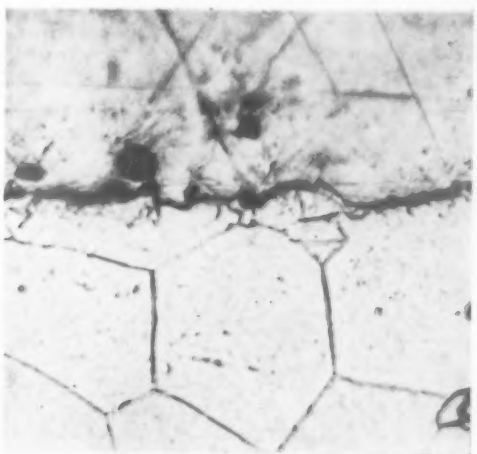

Fig. 7 Shows condition at interface when metallic spray bonding method is used. Mag. 1000 ×

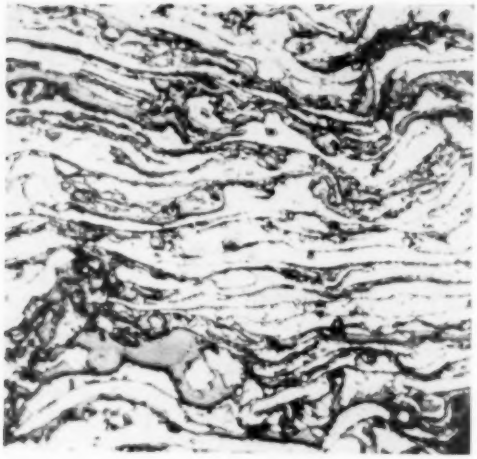

Fig. 8 Characteristic microstructure of sprayed steel deposit showing layers of metal and oxide. Mag. 1000 ×

larities and with each other or by cold welding at regions where the oxide film is disrupted on impact and metal to metal contact obtains.

Since sprayed coatings exhibit a lamellar type of structure as shown by Fig. 8, they have directional properties and have a greater tendency to split in a direction parallel to the long axis of the lamellae. On grooved or threaded surfaces, this tendency is decreased as the flakes are not flat, but conform to the shape of the groove or threads. Cavities between adjacent flakes and oxide inclusions tend to make sprayed coatings porous and lower in density than the same metal in cast or wrought forms. This porosity makes the coatings more satisfactory for bearing surfaces as the pores will hold lubricants and the porous sprayed metal will provide an excellent surface for holding paint or other protective organic coatings.

For some applications, the structures and properties of sprayed coatings limit their application. These coatings are brittle and have low elongation and tensile strength. Because of these conditions, sprayed coatings should not be used where they will be subject to direct impact or appreciable flexing.

Fig. 9 Typical arrangement for repairing worn part by metallizing with part mounted in lathe and metallizing gun attached to tool post in carriage

APPLYING METALLIZED COATINGS

In metallizing, it is most essential to have clean, suitably prepared fresh surfaces before spraying. All oil or other contaminants should be removed and the surface roughening treatment should be accomplished dry. Spraying should be done as quickly as possible after the surfaces are prepared to avoid changes resulting from rusting or other contamination. The spraying procedure in building-up a coating is much like paint spraying and is not difficult to learn. Any operator familiar with the use of a paint spray gun or a welding torch can soon become skilled in operating a metallizing gun. A typical set-up for repairing a worn cylindrical part by applying a sprayed steel layer is shown in Fig. 9.

APPLICATIONS OF METALLIZING

The principal applications of the metallizing process are for repairing worn machine elements or reclaiming mismachined parts and for protecting many different types of equipment and structures from corrosive attack in a variety of corrosive environments.

For repair work on machine elements, the metallizing process is especially adaptable for building-up worn shafts, rods, pistons, lathe beds and other machine elements with soft or hard steels or special hard alloys to restore them to their original dimensions so they may continue to be serviceable. The properties and bond strengths of the sprayed deposits are entirely adequate to permit the parts to be machined or ground and to provide satisfactory performance in service.

For protecting equipment and structures against corrosive attack in different environments, metallizing has the advantage that much thicker coatings of the protective metals can be applied more readily than with other conventional coating methods such as dipping or electroplating. Owing to the porosity of metallized coatings, it is customary to apply coatings of greater thickness than for dipped or plated coatings or to employ some additional protection to seal the pores. For many applications, metallized coatings of either aluminum or zinc are employed in thickness ranging from 3 mils to 15 mils. Furthermore, these coatings can be applied to large assemblies and structures in place because metallizing equipment is portable and can be brought to the work. In instances where protection against corrosion is the important criterion, coatings of 3 to 15 mils of aluminum or zinc provide better and more lasting protection against corrosive attack than most paint systems. The appearance of typical cross sections of metallized coatings of aluminum and zinc applied to grit-blasted steel for protection against corrosion is shown by Figs. 10 and 11. While thin flash coatings can be applied, the usual

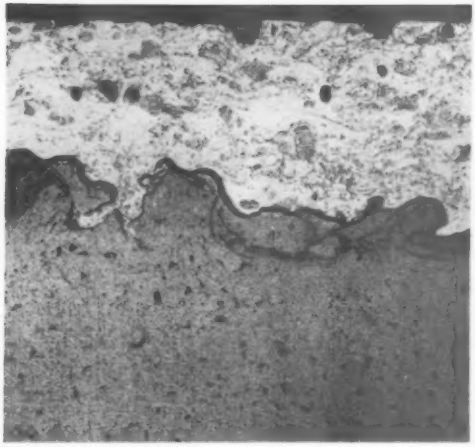

Fig. 10 Cross section of metallized coating of aluminum on grit-blasted steel. Mag. 100 ×

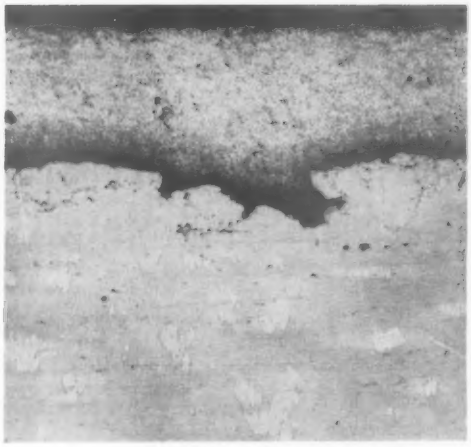

Fig. 11 Cross section of metallized coating of zinc on grit-blasted steel. Mag. 100 ×

thickness of coating applied in one pass is about 3 mils. Thicker coatings are formed by multiple passes with the metallizing gun.

Metallized coatings of aluminum and zinc are commonly used for protecting iron and steel from atmospheric corrosion as well as from fresh and salt water immersion. These coatings provide protection against corrosion not only by covering the surface with a more corrosion resistant metal, but also by galvanic action since both aluminum and zinc are anodic to iron and steel. Under these circumstances, the porosity of the coating is not important. All of the other commonly sprayed metals are cathodic to iron and will not provide effective protection unless they are extra thick and have their pores sealed by some appropriate method. Sprayed coatings of lead are used for obtaining resistance to acids or other strong reagents, while coatings of tin are employed for protection of food vessels. Such coatings of lead or tin, however, must be completely sealed to be satisfactory.

While sprayed aluminum and zinc coatings provide excellent protection for many applications, they may also be painted for appearance or coated with materials such as chlorinated rubber or vinyls to provide still additional protection. When painting is to be done, it is possible to use thinner sprayed coatings as the porous sprayed metal provides a very satisfactory base for painting and paint coatings will adhere better to metallized surfaces and last longer. In addition, the paint will seal the pores of the sprayed metal and protect it from sacrificial attack. The combination of metallized and paint coatings offers some interesting possibilities for providing extra good protection against severe corrosive conditions.

Metallized coatings have been applied to many different items over the last 20 years and this experience has been helpful in determining the thickness and type of coating to be used and in predicting the probable life of these coatings. Water storage and butane storage tanks which have been metallized have given excellent service for many years. Other applications of metallizing, such as for ship hulls, superstructures, docks, piling, and buoys, underframing of railway cars, deck girders on railway bridges, dam gates, refrigeration and air conditioning units, vapor degreasers and pole line hardware illustrate some of the fields where this process can be employed to advantage.

Another useful application of metallizing is for the protection of steel melting pots, salt pots, annealing box covers and pyrometer tubes against oxidation and scaling during use at elevated temperatures. Such heat resistant coatings are made by spraying the prepared steel surface with aluminum. Then, the sprayed surface is coated with a special sealer containing a metallic powder. After this, the coated article is heat treated to diffuse the aluminum into the steel and form a heat resistant surface coating.

The author wishes to acknowledge with thanks the source materials, samples and illustrations furnished by R. J. McWaters of the Metallizing Engineering Co.

Heat Treating Properties of Low Hydrogen Electrode Weld Metals

Matching the mechanical properties of rolled or cast steel with the weld metal requires an adjustment of the alloy composition of the electrode and the type of electrode coating

by D. C. Smith and W. G. Rinehart

A KNOWLEDGE of the heat-treating properties of weld metals is necessary in selecting the proper electrodes for welding aircraft steels, alloyed-steel castings and other high-tensile steels that have to be subsequently heat treated to get the optimum results from the weldment. The development of the low-hydrogen type electrode coating has made it possible to produce weld metal of any desired analysis to fit a given heat treatment.

Information on the mechanical properties of steels heat treated in various ways is available in many handbooks and steel company catalogs, but unfortunately there is very little published on the properties of alloy-weld metal. Lack of this information creates a problem for the fabricator and, as a consequence, may result in the improper application of the electrode or it may result in the failure of a weldment which could have been successful had the proper information been available. Perhaps one of the greatest reasons for the lack of this published information is due to the relative newness of the electrode business. There has been very little published on the properties of low-carbon (<0.15%) alloy steels and since weld metal compositions are generally of a low carbon content the published mechanical data for rolled and cast steels are not always applicable to weld metal.

High-hardenability steels which were formerly purchased on the basis of chemistry are now being purchased according to a hardness specification as measured by the Jominy test; hence the Jominy curves of weld metal often are desirable.

It has been our experience in designing electrodes that matching the analysis of the parent metal does not necessarily match the mechanical properties of rolled or cast steel. Generally a reduction of carbon with a readjustment of alloy composition is necessary. Thus a purchase specification based upon the chemical analysis of the weld deposit, unless the mechanical properties are known, is not adequate.

In order to better understand the difference between the low-hydrogen and the more conventional types of electrodes, a comparison chart of the coating composition of the principal types is given in Table 1. Groups

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Paper was presented before the Thirty-Second Annual Meeting, AWS, Detroit, Mich., week of Oct. 15, 1951.

Table 1—Basic Coating Composition of Mild Steel Metallic Arc Welding Electrodes

Coating materials	*Group 1*		*Group 2*		*Group 3, E6020, E6030*	*Group 4, E6015, E6016*
	E6010	*E6011*	*E6012*	*E6013*		
Organics, Gums, Resins, Cellulose	●	●	O	X	O	..
Feldspars, Alkali Aluminum Silicates	O	O	X	X	O	..
Clays, Aluminum Silicates	O	O	O	O	O	O
Talcs, Magnesium Silicates	O	O	O	O	O	..
Asbestos	X	X	O	O	O	..
Silica	..	..	..	..	X	..
Titanates, Rutile TiO_2, Sodium and Potassium Silicates	X	X	●	●	..	X
Iron Oxide	..	..	O	O	●	O
Calcium Carbonate	O	O	O	O	O	●
Calcium Fluoride	..	..	..	..	..	X
Potassium Silicate	..	X	O	●	..	X
Sodium Silicate	●	O	●	O	X	X
Ferro Manganese	X	X	X	O	●	X
Ferro Silicon	..	..	..	..	..	X

O = Small quantities or optional. X = Medium quantities. ● = Large quantities.

1, 2 and 3 have in common organics, silicates, titanates together with oxidizing and reducing agents. Group 1 is predominantly organics; Group 2, titanates; Group 3, iron oxide. In low-hydrogen Group 4 calcium carbonate, calcium fluoride, and titanates are the predominant ingredients. The high calcium-carbonate content produces a very alkaline slag in contrast to the other groups.

Mathias and Bunk[6] and Claussen[7] have very adequately compared the properties of the various electrode coatings and their influence on the property of weld metal.

In Groups 1, 2 and 3 (Fig. 1), the organics vary from a few per cent to a maximum of around 40 percent and the hydrogen gas in the arc atmosphere varies between 20 to 40 percent. In Group 4 no organic materials are added in the coating and the electrode is generally baked out at high temperatures to reduce the moisture or potential hydrogen to a minimum. Available data indicate that the higher the tensile strength of the weld metal the lower the moisture or potential hydrogen content of the coating should be for best results.

Several explanations for the detrimental effects of hydrogen in the weldment have been given. It is pretty well agreed that hydrogen in the arc dissolves in the molten metal and migrates to the surrounding heat-affected areas and may cause cracking if the cooling rate is too rapid when welding steels of high hardenability. Hydrogen-free welds made under similar conditions usually produce sound weldments.

Schaeffler, Campbell and Thielsch[8] are publishing a literature review of all the available information on the effect of hydrogen in weld metal under the auspices of the Literature Advisory Committee of the Welding Research Council.

A very important difference between the low-hydrogen group and the others is its property to transfer alloys efficiently from the coating through the arc stream into the weld metal. This property enables a more positive control of the weld-metal analysis which is becoming highly important in the welding of high-strength alloy steels.

Perhaps the greatest contributing factors for this efficient alloy transfer are in the globular transfer of the weld metal and the very close arc that can be used in welding. With this type of coating it is possible to maintain a positive control of the alloys in the weld deposit, and likewise carbon introduced in the proper form through the coating can be controlled to a very close range. Hence with this ability of controlling carbon and alloys in the weld metal it is possible to make electrodes which will give various mechanical properties through suitable heat treatment.

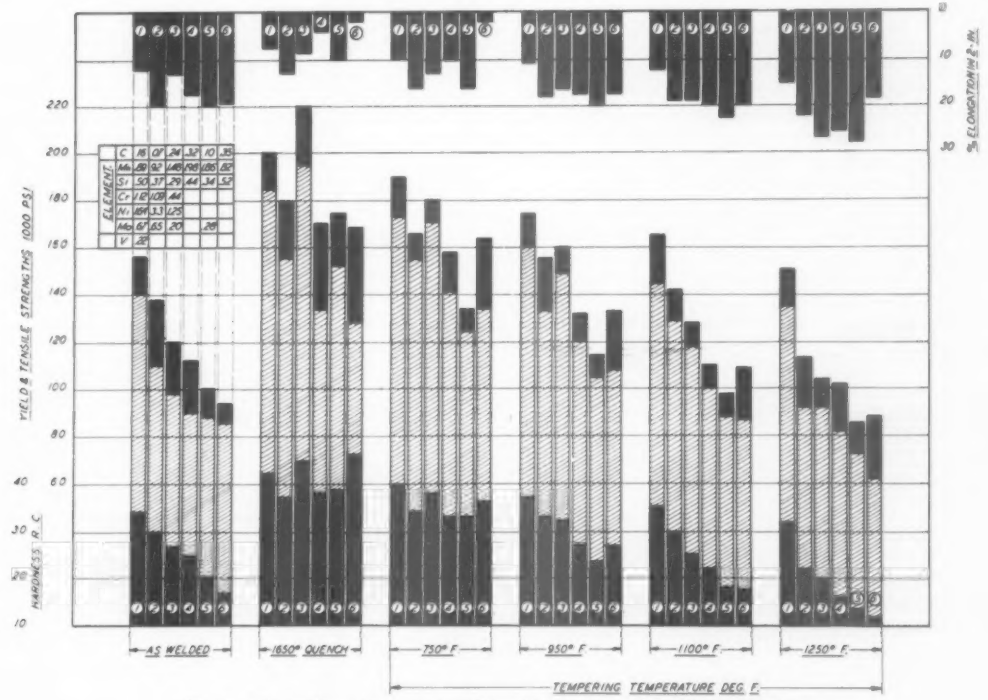

Fig. 1 Effect of heat treatment on 6 low-hydrogen weld metal compositions

PREPARATION OF TEST SPECIMEN

1. *Plate Material.* Mild steel, $^3/_4$ in. thick, ASTM designation A285 or A7. The scarfed edges in all tests were clad with two layers of weld metal.

2. *Tensile specimens* were prepared according to ASTM-A233–48T with the exception of the heat-treated ones. These were premachined to a 0.565 diameter before heat treatment and afterward finished to 0.505.

3. *Hardness Specimens.* The 0.505-tensile specimens were used for determining the Rockwell C hardness.

4. *Jominy Hardness.* A pad of weld metal, $1^1/_4$ x 2 x 8 in., was built up on mild steel, then cut off and turned to the standard Jominy test bar.

5. *Charpy Impacts (Keyhole Notch).* Part of the specimens were cut from the top half of a weld metal pad, 1 x 3 x 10 in., deposited on a 2- x 4- x 10-in. steel bar, and part were cut from the top half of a single-V butt weld. The difference between the two types of specimens was found to be negligible and thus not reported. The standard Charpy Keyhole notch was machined from the top side of the weld metal with notch perpendicular to plate surface and centered in weld metal. (See Fig. 1A). All heat treating was done after removing the weld pad from the steel bar on which it was deposited, but before machining the individual specimens.

HEAT TREATMENT

1. Quenched and Tempered. The specimens were held at 1650° F. for 1 hr. and those having a carbon content less than 0.20 percent were water quenched while those of higher carbon were oil quenched. They were held at the tempering temperature for 1 hr. and cooled in still air, unless otherwise noted.

2. Stress Relieving. All specimens stress relieved were held for 1 hr. at 1150° F. and furnace cooled at the rate of approximately 60° F. per hour, or as otherwise noted.

3. Jominy Hardenability. Standard ASTM-A255–48T specification was followed in making the Jominy curves.

HEAT TREATING HIGH-STRENGTH ELECTRODES

Metallic arc-welding electrodes have been designed in the past largely for fabricating metals based either on their mechanical properties of tensile and yield strengths, ductility, weld soundness and usability, or upon the chemistry of the weld deposit. Examples of electrodes designed for the chemistry of the weld metal instead of physical properties are the chromium-molybdenum, and straight nickel groups. In these the physical properties are generally secondary in importance. The chemistry of the weld metal is selected to prevent creep, reduce graphitization and improve notch toughness at low temperatures.

Until recently little effort was made in the design of electrodes for repair welding of castings, to match the heat-treating properties or chemistry of the casting being repaired. Lack of the proper electrodes and information on the application and procedure have in many cases resulted in poor quality of repair welds. The low-hydrogen electrode development now makes it possible to repair defects in castings with weld metal equal in soundness to the casting proper, and many of the large steel casting manufacturers are now using low-hydrogen electrodes with excellent results.

We have been requested by industry to develop weld metal compositions to meet various heat-treating conditions. This paper gives our heat treating results on six different weld metal compositions. The selection of these six was made because of the wide range of carbon and varied alloy composition. The analysis of the weld deposits and the effect of heat treatment on the mechanical properties and hardness are shown in Fig. 2 and Table 2.

Figure 3 shows the Jominy hardness curves, and Figs. 4 to 8 give the effect of tempering on the impact strength of each of these electrode weld deposits.

It is realized that the heat treatment employed in this study would not always be applicable to that used in practice. Nevertheless it is believed that it represents the most general procedure followed and gives a condition under which a comparative evaluation can be made.

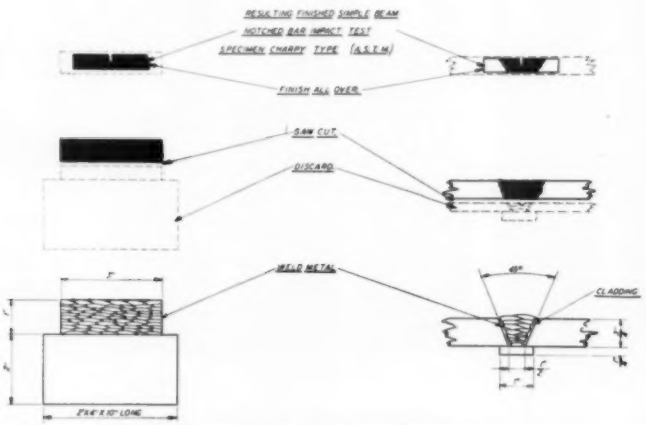

Fig. 1A Preparation of the Charpy Impact Specimen

DISCUSSION OF RESULTS

The response to heat treatment of

Table 2—Effect of Heat Treatment on the Mechanical Properties of 8 Low-Hydrogen Electrode Weld Metals

Heat treatment	*Weld metal No.*	*Tensile strength, psi.*	*Yield strength, psi.*	*Elongation, % in 2 in.*	*Reduction of area, %*	*Hardness, Rockwell C*
As-welded	1	156,000	141,000	11.0	24.0	34
	2	138,500	108,750	20.0	57.3	30
	3	120,000	97,500	13.0	20.0	27
	4	111,000	90,000	17.5	40.0	25
	5	100,500	87,500	20.5	46.0	21
	6	96,500	87,500	19.0	35.7	17
	7	120,500	115,000	21.5	57.0	25
	8	104,000	96,000	23.0	65.0	22
1150° F., stress relieved	1	161,500	147,500	15.0	49.0	..
	2	136,000	112,500	14.0	31.0	..
	3	111,000	82,000	22.5	55.0	..
	4	93,250	85,000	23.0	50.0	..
	5	91,500	73,000	28.5	69.0	17
	6	85,750	61,250	26.0	64.0	..
	7	132,000	122,000	14.5	35.0	29
	8	109,000	99,000	24.5	62	26
1650° F. quench	1	200,000	185,000	7.0	17.0	42
	2	179,750	147,500	14.0	54.7	37
	3	222,500	195,000	8.0	29.0	44
	4	170,000	132,500	4.0	10.0	38
	5	174,000	152,500	10.0	31.0	39
	6	166,000	127,500	4.0	..	46
	7	155,250	146,250	11.0	49.0	33
	8	128,750	117,500	18.0	60.0	29
1650° F. quench, 750° F. temper, air cool	1	186,000	176,000	10.0	37.0	40
	2	166,000	156,500	15.0	..	34
	3	181,250	175,000	12.5	49.0	38
	4	159,500	142,500	10.0	43.0	33
	5	123,250	113,500	17.0	60.0	28
	6	165,000	134,000	4.0	..	36
	7	148,000	141,250	13.0	49.0	32
	8	115,000	107,500	21.0	67.0	25
1650° F. quench, 950° F temper, air cool	1	174,000	160,000	11.0	40.0	38
	2	156,750	132,500	17.0	57.0	33
	3	160,000	150,000	16.0	57.0	32
	4	131,250	120,000	16.5	52.0	27
	5	113,500	103,750	20.0	64.0	23
	6	134,000	119,500	16.5	63.0	27
	7	135,500	125,000	18.0	55.0	28
	8	106,250	97,250	19.5	65.0	22
1650° F. quench, 1100° F. temper	1	164,500	144,500	13.0	41.0	35
	2	141,000	134,000	18.0	62.0	30
	3	130,000	118,000	18.5	62.0	25
	4	115,500	98,750	21.5	62.0	22
	5	101,600	90,200	22.0	70.0	18
	6	108,000	85,750	20.5	52.0	18
	7	143,500	137,500	17.5	52.0	31
	8	115,500	107,500	18.5	65.0	26
1650° F. quench, 1250° F. temper	1	150,000	135,000	15.0	49.0	34.0
	2	116,000	92,500	21.5	62.3	22.0
	3	107,500	92,500	26.0	65.0	20
	4	101,500	84,000	25.0	57.0	17
	5	86,400	75,300	27.5	72.0	13
	6	87,500	61,750	19.0	39.0	12
	7	117,750	109,500	20.0	57.0	22
	8	102,500	95,900	25.0	67.0	18

a steel is largely determined by the carbon content, but of the usual alloys employed, chromium and manganese are next in effectiveness. The hardening effect on the weld metal of the other common alloying elements used—namely, silicon, nickel, molybdenum and vanadium—due to quenching is small. In this study the carbon content ranges from 0.07 to 0.35 percent and its effect on the surface hardness is clearly shown in the Jominy curves (Fig. 3). The effect on the depth hardening due to the alloys in the weld metal is likewise brought out in the Jominy curves.

The results of this investigation as shown in Figs. 2 and 3 indicate that the weld metal responds to heat treatment similarly to that of steel with a comparable composition. In tempering to a desired hardness or tensile strength the effect of the alloying elements is very pronounced. Electrode weld metal No. 3 quench hardens to approximately 44 Rockwell C hardness, yet the tensile strength and ductility are exceptionally good. The values at the different tempering temperatures also show that this weld deposit can be controlled for strength and hardness very closely. Comparing it with weld metals Nos. 1 and 2 where the carbon content is lower but the strength-giving alloys, such as chromium, molybdenum and vanadium, are higher, the quench hardening and the effect of the tempering temperatures are not so pronounced. A comparison of weld metals Nos. 4 and

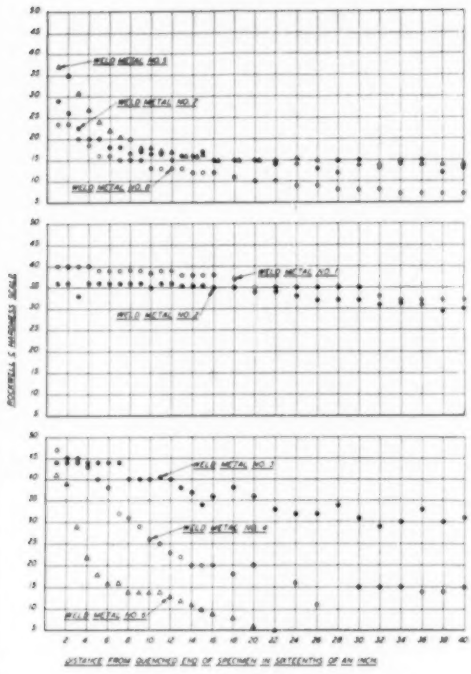
WELD METAL NO. 1
WELD METAL NO. 2
WELD METAL NO. 3
WELD METAL NO. 4
WELD METAL NO. 5
WELD METAL NO. 6
WELD METAL NO. 7
ROCKWELL C HARDNESS SCALE
DISTANCE FROM QUENCHED END OF SPECIMEN IN SIXTEENTHS OF AN INCH

Fig. 2 Jominy hardenability curves

6, Figs. 2 and 3, shows why manganese steels are preferred over the straight carbon steels.

The impact strength as shown in Figs. 4 to 8 were exceptionally uniform and bring out the fact that high-quality weld metal is produced with the low-hydrogen type electrode. Stress relieving at 1150° F. for 1 hr. did not improve the notch toughness in weld metals Nos. 1 and 2. In weld metal No. 3 where the carbon content is higher and the alloys lower, stress relieving at 1150° F. was beneficial. In fact, this composition of weld metal responded to all the different heat treatments very satisfactorily, whereas weld metals Nos. 1 and 2 require at least a 1250° F. tempering temperature for satisfactory impact strength over the range of temperatures tested. A comparison between weld metals Nos. 4 and 6 (Figs. 7 and 8) shows the beneficial effect of manganese on the impact strength, particularly in the 1250° F. tempered condition.

Weld metals Nos. 1 and 2 have a considerably higher tensile strength in the as-welded condition due to their high alloy content which of course is the reason for their greater depth hardening as shown in the Jominy curves, Fig. 3. Since the tensile and hardness (Fig. 2) are considerably higher it is only natural that their impact strength is lower in this condition. It was somewhat disturbing that weld metal No. 2 (Fig. 5) with the high nickel content did not have a

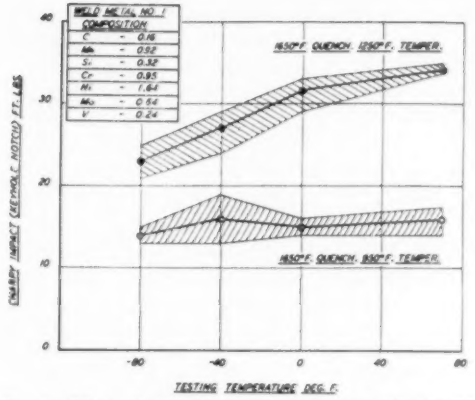

Fig. 3 Effect of tempering on impact strength of weld metal No. 1

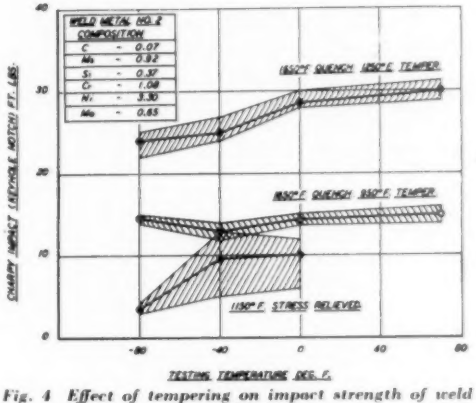

Fig. 4 Effect of tempering on impact strength of weld metal No. 2

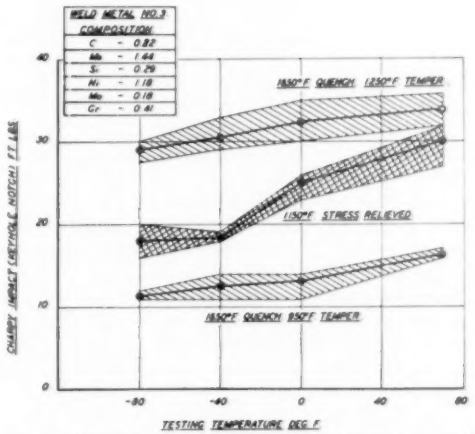

Fig. 5 Effect of tempering on impact strength of weld metal No. 3

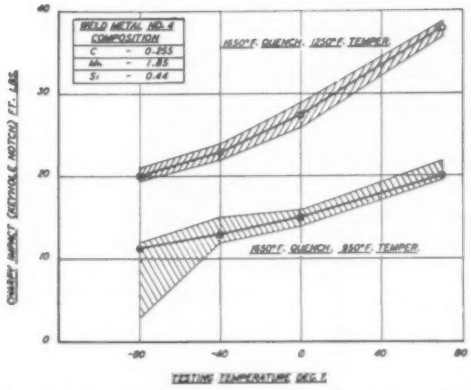
WELD METAL NO. 4
COMPOSITION
C - 0.055
Mn - 1.85
Si - 0.44
1650° F. QUENCH, 1250° F. TEMPER.
1650° F. QUENCH, 950° F. TEMPER.
CHARPY IMPACT (KEYHOLE NOTCH) FT. LBS.
TESTING TEMPERATURE DEG. F.

Fig. 6 Effect of tempering on impact strength of weld metal No. 4

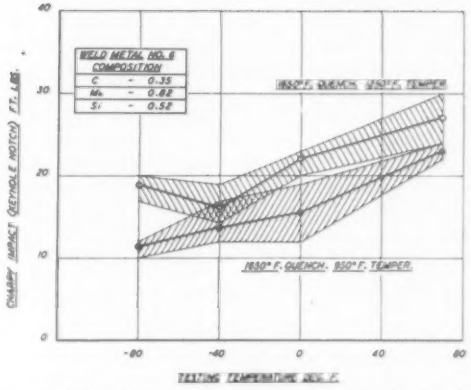
WELD METAL NO. 6
COMPOSITION
C - 0.35
Mn - 0.82
Si - 0.58
1650° F. QUENCH, 1250° F. TEMPER.
1650° F. QUENCH, 950° F. TEMPER.
CHARPY IMPACT (KEYHOLE NOTCH) FT. LBS.
TESTING TEMPERATURE DEG. F.

Fig. 7 Effect of tempering on impact strength of weld metal No. 6

higher impact strength than weld metal No. 1 when its tensile strength was approximately 40,000 psi. lower in the 1250° F. tempered condition. However, at −80° F. the impact strength curve of weld metal No. 1 was decreasing sharply, whereas with the weld metal No. 2 the curve was leveling off, indicating its superior impact strength at this low temperature. One of the foundries using this weld metal No. 2 gives it a double draw at 1250° F. and this improves the impact but as yet we have not checked the double draw treatment.

The selection of electrodes for a given job should be fairly simple when given all this information on their heat-treating properties. If, however, the physical properties and hardness data are available in the

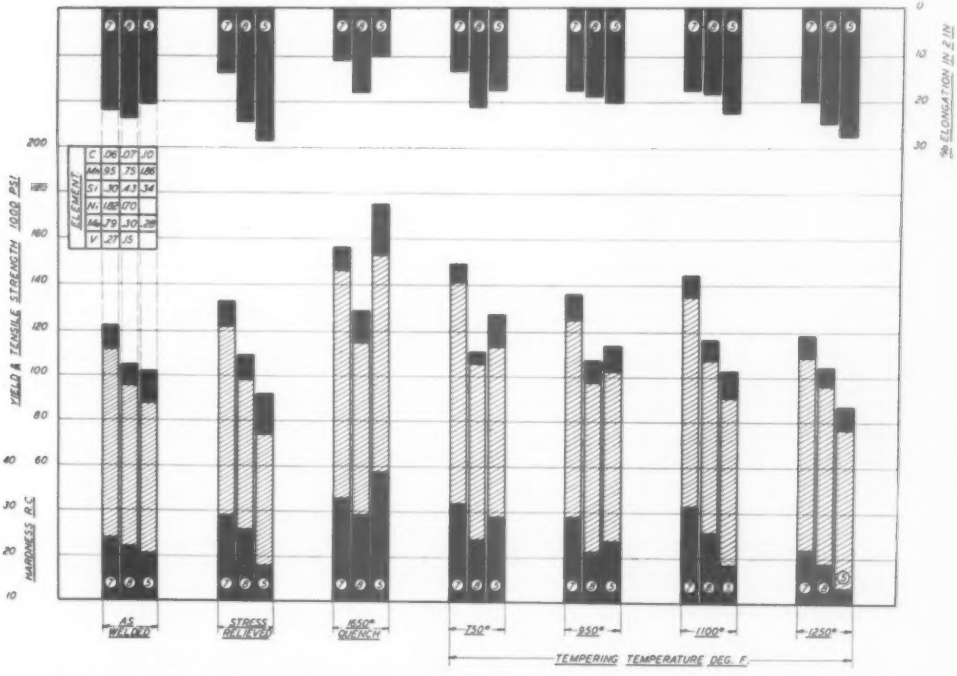

Fig. 8 The effect of heat treatment on 3 low-hydrogen high-tensile fabricating electrode weld metals

as-welded state only, it may be very confusing and difficult to make the proper selection. No. 3 Electrode was designed to match the properties of AISI 4130, 8630 and similar steels, and this study has shown that they match very closely. No. 1 was designed for use with 4340 type steels. No. 4 matches fairly closely the properties of the popular type manganese-carbon steels, and No. 6 that for the 1035 and 1040 straight carbon steels. No. 2 was developed for repairing castings of similar composition.

HIGH-TENSILE FABRICATING ELECTRODES

Inasmuch as many electrodes are used for both fabricating and heat-treating purposes, we have investigated two types which are being used successfully for welding steels of high hardenability. One of these is referred to as the moly-manganese[1,2] and the other, a more recent development, a nickel-moly-vanadium type.[3] During World War II the moly-manganese type was developed and used successfully both as a fabricating electrode for making strength welds and for repairing castings which were to be given a subsequent heat treatment. For making strength welds on high-tensile plate a preheat was

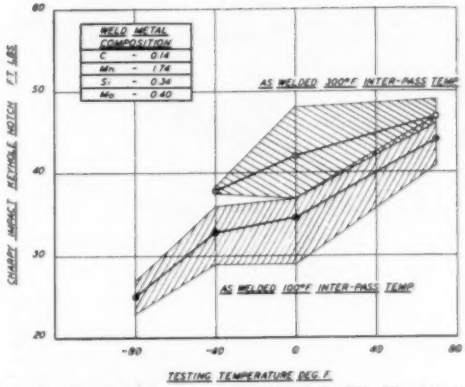

Fig. 9 As-welded impact strength of the Mn-Mo, 100,000 psi., low-hydrogen weld metal No. 5

Table 3—Effect of Various Heat Treatments on the Impact Strength of the Ni-Mo-V-100 Psi. Low-Hydrogen Weld Metal No. 8

Test No.	Heat treatment	Testing temperatures, ° F. +70	Av.	0	Av.	−40	Av.	−80	Av.
7850	As-welded, 100° F. interpass	40 43 51	45	41 39 39	39.6	35 42 34	37	31 38 30	33
8271	temperature	40 44 44	43	36 36 35	35.6	35 34 34	34.3	.. .. ..	..
8272	As-welded, 300° F. interpass temperature	42 44 44	43.3	30 41 37	36	34 53 46	44	.. .. ..	..
8271A	950° F., 1 hr. and F. C.*	43 42 ..	42.5	.. .. ..	..	30 31 30	30.3	.. .. ..	..
7850A	1150° F., 1 hr. and F. C.	28 30 29	29	23 22 23	22.6	21 24 26	24	24 26 22	24
8301	1150° F. 5 hr. and F. C.	29 31 32	30.6	27 30 27	28	23 26 26	25	.. .. ..	..
8301A	1150° F. 10 hr. and F. C.	35 33 34	34	27 28 28	27.6	27 23 21	23.6	.. .. ..	..
8271B	1250° F. 1 hr. and F. C.	36 34 35	35	.. .. ..	..	25 27 26	26	.. .. ..	..
	1650° F. W. Q.† and								
8272B	950° F. 1 hr. and air cool	44 43 46	44.3	.. .. ..	..	33 36 34	34.3	.. .. ..	..
8272A	1100° F. 1 hr. and air cool	34 41 37	37.3	.. .. ..	..	24 30 27	27	.. .. ..	..
7850B	1250° F. 1 hr. and air cool	42 39 41	40.7	42 35 41	39.3	30 32 28	30	30 25 25	26.6

* F. C., furnace cool.
† W. Q., water quench.

Table 4—Effect of Various Heat Treatments on the Impact Strength of the Ni-Mo-V, 120 Psi. Low-Hydrogen Weld Metal

Test No.	Heat treatment	Testing temperatures, ° F. +70	Av.	0	Av.	−40	Av.	−80	Av.
7851	As-welded, 100° F. interpass	30 32 29	30	39 28 29	32	27 25 23	25	31 14 16	17
8507	temperature	27 26 27	26.6	27 27 27	27	19 22 23	21.3	.. .. ..	..
8474		29 27 28	28	19 25 22	22	24 20 35	25	.. .. ..	..
8471	As-welded, 300° F. interpass	.. 35 ..	35	26 27 24	25.6	21 21 25	22.3	17 17 ..	17
8508	temperature	34 28 50	37.3	26 22 24	24	22 20 21	21	.. .. ..	..
8274A	1050° F. 1 hr. and F. C.*	23 22 23	22.6	.. .. ..	..	4 12 4	6.8	.. .. ..	..
7851A	1150° F. 1 hr. and F. C.	23 18 20	20.3	31 11 21	21	18 5 4	9	3 3.5 3	3.2
8507A	1150° F. 1 hr. and F. C.	.. .. ..	..	.. .. ..	..	5 11 4	7	.. .. ..	..
8273B	1250° F. 1 hr. and F. C.	32 33 34	33	.. .. ..	..	22 8 ..	15	.. .. ..	..
8675	1250° F. 2 hr. and F. C.	.. .. ..	..	.. .. ..	..	15 13 17	15	.. .. ..	..
8274B	1350° F. 1 hr. and F. C.	28 40 ..	34	.. .. ..	..	30 33 31	31.3	.. .. ..	..
8674	1350° F. 1 hr. and F. C.	.. .. ..	..	.. .. ..	..	27 27 27	27		
8673	1650° F. 1 hr. and F. C.	.. .. ..	..	.. .. ..	..	26 34 26	30		
						33 30 ..	..	.. .. ..	..
	1650° F., W. Q.† and								
7851B	1250° F. 1 hr. and A. C.	41 39 31	37	25 23 25	24.3	18 25 29	24	19 20 20	19.8
8302A	1250° F. 1 hr. and W. Q.	25 24 25	24.6	.. .. ..	..	17 12 6	11.7	.. .. ..	..
8302B	1250° F. 4 hr. and W. Q.	39 30 34	34.5	.. .. ..	..	29 27 28	28	.. .. ..	..
8302	1250° F. 1 hr. and F. C.	27 28 28	27.8	.. .. ..	..	19 3 3	8.3	.. .. ..	..

* F. C.—furnace cool.
† W. Q.—water quench.

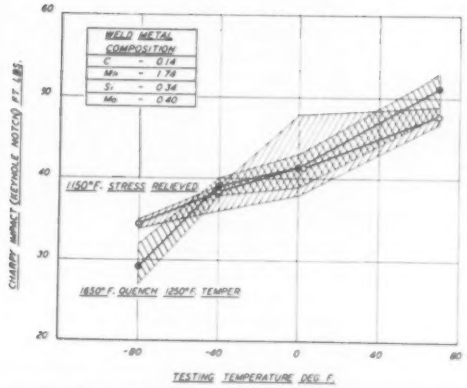

Fig. 10 Effect of stress relieving and tempering on impact strength of the Mn-Mo, 100,000 psi., low-hydrogen weld metal No. 5

necessary when fabricating thicknesses over approximately one-half inch.

The nickel-moly-vanadium type was developed to be used without preheat. With this type a wide range of physical properties can be obtained by varying the percentage composition of these alloys but at present we have investigated only two strength levels, 100,000 and 120,000 psi. as required by the latest military electrode specification MIL-E-986. The weld metal analysis for the 120,000 psi. studied was the one given by Franks and others.[3] Figure 9 shows the chemical analysis and mechanical properties of the three electrode weld deposits, as-welded, stress relieved, quenched and tempered. Tables 3 and 4 and Figs. 10 to 15, inclusive, give the Charpy impact strengths as-welded and under various heat-treating conditions. Figure 10 shows the effect of preheat and interpass temperature on the impact strength of weld metal No. 5. Figure 3 shows the Jominy hardness curves.

DISCUSSION OF RESULTS

The properties of the two types of electrodes are quite different in their response to heat treatment. The nickel-moly-vanadium 100 psi., weld metal No. 8, increases very little in hardness and tensile strength when quenched from 1650° F., whereas the manganese-moly 100 psi., weld metal No. 5, increases from 100,000 psi., as-welded, to 174,000 psi. with the corresponding increase in hardness, Fig. 9. Tempering reduces both hardness and tensile strength uniformly in nearly a straight line function. The Ni-Mo-V 120 psi., weld metal No. 7, follows a similar pattern as weld metal No. 8, but shows a slightly higher increase in tensile strength and hardness on quenching from 1650° F. Stress relieving at 1150° F. increased the tensile

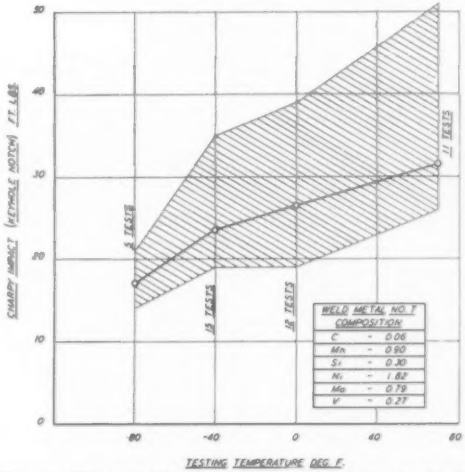

Fig. 12 The as-welded impact strength of the Ni-Mo-V, 120 psi., low-hydrogen weld metal No. 7

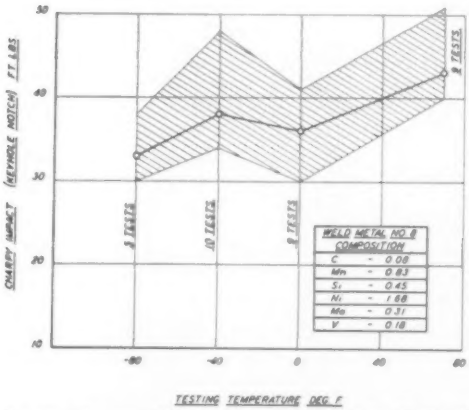

Fig. 11 The as-welded impact strength of the Ni-Mo-V, 100 psi., low-hydrogen weld metal No. 8

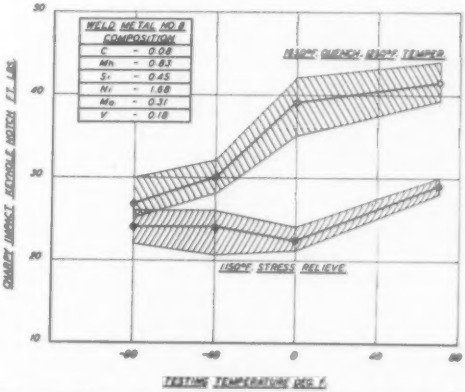

Fig. 13 Effect of stress relieving and tempering on the impact strength of the Ni-Mo-V, 100 psi., weld metal No. 8

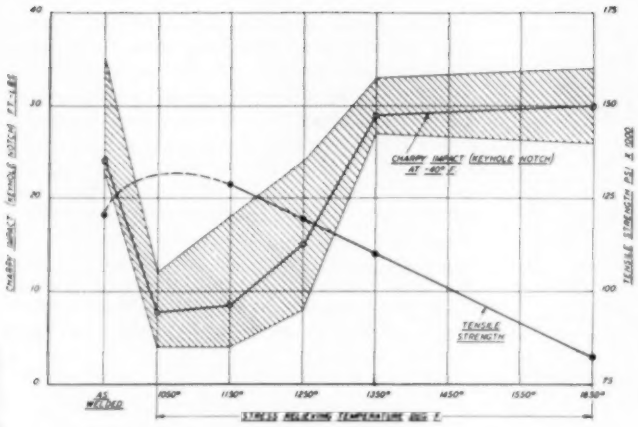

Fig. 14 Effect of various stress relieving temperatures on impact and tensile strength of the Ni-Mo-V, 120 psi., weld metal No. 7

strength of the Ni-Mo-V type from 7 to 10% over the as-welded, whereas, the Mn-Mo type was reduced about the same amount.

The impact strength in the stress-relieved condition shows a marked difference between the two, Figs. 11 and 14. In the Mo-Mn type the impact values follow a pattern like that of a conventional tough heat-treatable steel. The heat treatment, both in the stress-relieved and quenched and tempered state, lowers the tensile and increases the ductility and impact strengths in the expected manner. In the Ni-Mo-V type stress relieving at 1150° F. increases the tensile and lowers the impact strength (Figs. 10, 11, 12 and 14 and Table 2). The effect on the impact strength due to stress relieving at 1150° F. is more pronounced on the 120,000 psi. than on the 100,000 psi. grade. Since the only difference in weld metal composition is the larger amounts of molybdenum and vanadium the influence of one or both of these alloys at temperatures around 1150° F. is responsible for this behavior. Some authorities[5] attribute this to a carbide precipitation in the range of 900 to 1200° F. The data given in Table 4 and Fig. 15 confirm this embrittling temperature range and show that the heat treatment for the 120,000 psi. grade should be stress relieved above 1250° F., or quenched from above the critical temperature and tempered above 1250° F. for the optimum results in impact strength. While the impact strength of the 100,000 psi. grade is reduced by stress relieving at 1150° F., Fig. 14 and Table 2 show that it has not impaired its usefulness in the temperature range investigated. The effect of preheat and interpass temperature on the impact strength of weld metal No. 5 (Mo-Mn type) is shown in Fig. 10. This indicates that better impact strengths are obtained with the higher preheat which is not in agreement with Campbell's[4] results. There was no appreciable difference between the Ni-Mo-V type when welded at 100 and 300° F. interpass temperature (Tables 2 and 3).

Jominy hardness determinations were included in this study to bring out the difference in depth hardening, which is an important property of the weld deposit used in casting repairs that received a subsequent heat treatment for increasing hardness and toughness. The results of these determinations are shown in Fig. 3. While none of the three show an appreciable amount of depth hardening the moly-manganese type is much greater than either of the Ni-Mo-V electrodes.

The increase in tensile strength and hardness in the as-quenched state of the Mn-Mo type, shown in Figs. 9 and 16, illustrates quite clearly why this electrode can be used successfully for repair of alloy steel castings which are to receive subsequent heat treatment for hardening; on the other hand the Ni-Mo-V type can be used very successfully in the repair of castings that are to receive no subsequent heat treatment.

In making a choice between these two types of electrodes it would seem that the moly-manganese type is the better electrode for both strength and repair welding where the weldment is to be given a heat treatment for increasing strength and hardness after welding. On the other hand, the Ni-Mo-V type is to be preferred if the weldment is to be made with little or no preheat and no subsequent heat treatment. Experience over the past several years' use of both of these types shows that highly restrained weldments require from 150 to 200° F. more preheat for the Mo-Mn than the Ni-Mo-V type. While the Ni-Mo-V type is reduced in its impact strength by the usual stress-

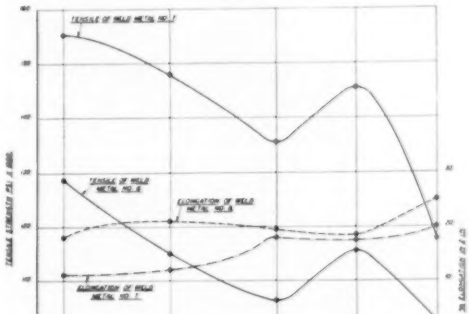
TENSILE OF WELD METAL NO. 7
TENSILE OF WELD METAL NO. 8
ELONGATION OF WELD METAL NO. 8
ELONGATION OF WELD METAL NO. 7
QUENCH
TEMPERING TEMPERATURE DEG. F.

Fig. 15 The effect of tempering on the tensile strength of the Ni-Mo-V weld metals Nos. 7 and 8

relieving temperature, the reduction is not sufficient on the 100,000 psi. grade to impair the weldment. If the weldment is to be stress relieved when using the 120,000 psi. grade, temperatures above 1250° F. should be used for best results as shown in Fig. 15.

While these examples represent only a few of the conditions which may be encountered in the proper selection of a high-tensile electrode for fabrication or repair welding which require heat treatment, it is believed a study of this kind will provide a more intelligent approach to the problem.

References

1. Miller, O. O., Kristofek, F. C., and Aborn, R. H., "Development of Ferritic Weld Metal for Repair of Thick Cast Armor," NDRC Report M-631 (OSRD 6366, Dec. 5, 1945).
2. Miller, O. O., Kristofek, F. C., and Aborn, R. H., "Transformation of Austenite in a Manganese-Molybdenum Steel Deposited as Weld Metal," THE WELDING JOURNAL, **29** (9) Research Suppl., 450-s to 458-s (1950).
3. Franks, E. H., Gayley, C. T., Wooding, W. H., *Jnl. Am. Soc. Naval Engrs.*, **62**, (3) 601–619 (Aug. 1950).
4. Campbell, H. C., "Transformation of Austenite in a Manganese Molybdenum Steel Deposited as Weld Metal," THE WELDING JOURNAL, **30** (5), Research Suppl., 253-s to 254-s (1950).
5. Camp, J. M., and Francis, C. B., *The Making, Shaping and Treating of Steels*, Carnegie-Illinois Steel Corp., 5th ed., p. 967.
6. Mathias, D. L., and Bunk, A. P., THE WELDING JOURNAL, **26** (3) 209–217 (1947).
7. Claussen, G. E., *Ibid.*, **28**, (1) 12–24 (1949).
8. Schaeffler, A. L., Campbell, H. C., and Thielsch, H., Report to be published under the auspices of the Literature Advisory Committee of the Welding Research Council entitled "Hydrogen in Mild-Steel Weld Metal."

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CURRENT WELDING LITERATURE

Airplane Engine Manufacture. Welding Turbine Shafts and Wheels for Jet Engines, G. H. DeGroat. Machy. (N. Y.), vol. 58, no. 5 (Jan. 1952), pp. 179–83.

Airplanes, Fuel Tanks. Welding Aluminum Is No Problem. Industry & Welding, vol. 24, no. 12 (Dec. 1951), pp. 31–32, 61.

Aluminum and Aluminum Alloys. Corrosion Aspects of Fusion Welded Aircraft High-Strength Aluminum Alloys, L. W. Smith. Corrosion, vol. 7, no. 12 (Dec. 1951), pp. 423–437.

Automobile Manufacture. Aluminum Cylinder Heads Formed by New Method, F. Jardine. Automotive Industries, vol. 105, no. 12 (Dec. 15, 1951), pp. 34–35, 112.

Bicycles. Production of All-Welded Bicycle. Welding & Metal Fabrication, vol. 19, no. 12 (Dec. 1951), pp. 450–456.

Brazing. Aluminum Alloys. Newer Techniques, Latest Methods for Torch Brazing Aluminum. Industry & Welding, vol. 24, no. 11 (Nov. 1951), pp. 44–45, 47, 76–77.

Brazing. Assembly by Brazing, L. Jacobsmeyer. Metal Industry, vol. 79, no. 11 (Sept. 14, 1951), pp. 215–219; no. 12 (Sept. 21), pp. 244–245.

Brazing. Comparison of Heating Methods for Brazing, L. F. Spencer. Steel Processing, vol. 37, no. 12 (Dec. 1951), pp. 617–622; vol. 38, no. 1 (Jan. 1952), pp. 29–34.

Brazing, Steel. Stainless Brazed Without Fluxing, F. W. Beall. Steel, vol. 130, no. 2 (Jan. 14, 1952), p. 57.

Containers, Manufacture. Automatic Equipment to Seam Weld Containers, C. S. Seltzer. Welding Engr., vol. 36, no. 12 (Dec. 1951), pp. 38–42.

Dairies, Pipe Lines. Revolutionary Advance in Dairy Engineering: Permanent Welded Pipe Lines, C. R. Havighorst. Food Eng., vol. 23, no. 9 (Sept. 1951), pp. 74–79.

Dies, Repair. Welding for Die Repair, E. Brenner and E. Smith. Industry & Welding, vol. 24, no. 11 (Nov. 1951), pp. 31–32, 34.

Electric Commutator Brushes. Carbon Brushes for Welding Generators, C. W. Adams. Industry & Welding, vol. 24, no. 12 (Dec. 1951), pp. 38, 41–42.

Eye Protection. More About Cover Lenses. Industry & Welding, vol. 24, no. 11 (Nov. 1951), pp. 36–38.

Heat Exchangers. New Wrinkles in Heat Exchangers, C. B. Clason. Welding Engr., vol. 86, no. 11 (Nov. 1951), pp. 33–35.

Industrial Trucks, Electric. Re-Design for Welding at Baker Industrial Truck. Industry & Welding, vol. 24, no. 12 (Dec. 1951), pp. 48–49, 51–53.

Internal Combustion Engines. Welding & Lubrication Problems, C. W. Brett. Sci. Lubrication, vol. 3, no. 11 (Nov. 1951), pp. 29–30.

Light Metals. Welding Magnesium Alloys, R. L. Nelson and I. C. Mattson. Metal Industry, vol. 79, no. 23 (Dec. 7, 1951), pp. 475–477; no. 24 (Dec. 14), pp. 495–498.

Locomotive Manufacture. Oxyacetylene Cutting Speeds Output of Multiple Parts, H. S. Swan. Can. Machy., vol. 62, no. 11 (Nov. 1951), pp. 143–146, 148.

Machine Shop Practice. Heavy Weldments Machined Within 0.002 In. Am. Mech., vol. 95, no. 25 (Dec. 10, 1951), pp. 144–145.

Magnesium and Magnesium Alloys. 7th Annual Magnesium Association Meeting. Modern Metals, vol. 7, no. 11 (Dec. 1951), pp. 53–56, 58.

Metal Cladding. Clad Steel Bullet Jackets Conserve Copper and Zinc, E. J. Reardon. Steel, vol. 130, no. 3 (Jan. 21, 1952), pp. 68–69.

Natural Gas Pipe Lines. Automatic Welding on Pipe-Line Right-of-Way Demonstrated, P. Reed. Oil & Gas J., vol. 50, no. 15 (Aug. 16, 1951), pp. 148, 151.

Natural Gas Pipe Lines. Automatic Welding on Right-of-Way, P. Reed. Oil & Gas J., vol. 50, no. 26 (Nov. 1, 1951), p. 72.

Natural Gas Pipe Lines. Welding Costs Reduced One-Fourth Using Mobile Unit for Right-of-Way Double Jointing, R. L. Looney. Oil & Gas J., vol. 50, no. 15 (Aug. 16, 1951), pp. 149–150.

Oil Tanks, Nozzles. How to Install 12-In. Nozzles on Tank Filled with Oil, R. M. Carter. Oil & Gas J., vol. 50, no. 22 (Oct. 4, 1951), pp. 288, 290–291.

Oil Well Drilling. Substructure Support Facilitates Rig Handling, G. M. Wilson. World Oil, vol. 133, no. 5 (Oct. 1951), p. 119.

Oxygen Cutting. Flame Softening in Metal Fabricating Industries, W. B. Sharav. Steel Processing, vol. 37, no. 12 (Dec.), pp. 599–602, 613.

Oxygen Cutting. Powder Cutting of Metals, A. S. Park. Compressed Air Mag., vol. 56, no. 12 (Dec. 1951), pp. 328–329.

Oxygen Cutting. Powder Processes, New Industrial Tool, A. B. Kinzel, D. Swan, H. Biers and H. R. Pufahl. Inst. Welding—Trans., vol. 14, no. 5 (Oct. 1951), pp. 154–159; (discussion), p. 160.

Petroleum Pipe Lines. How to Interpret Radiographs of Pipe-Line Welding Defects, A. G. Barkow. Oil & Gas J., vol. 50, no. 22 (Oct. 4, 1951), pp. 177–180, 183, 186, 268–269, 271.

Pipe Fittings, Standards. Forged Steel Socket-Welding Fittings for Petroleum Industry. Brit. Standards Instn.—Brit. Standard 1684 (1950), 8 pp., 3s.

(Continued on page 323)

Preheating for Welding

A review of information and experience to produce crack-free welded joints under a wide variety of conditions

by Arthur B. Tesmen

ONE of the most troublesome features of the welding process is the danger of cracks developing in the weld metal or in the adjacent base metal zone.

Today's conditions serve to increase the normal risk of crack formation. One adverse factor is the pressure for stepping up output during the present emergency. Newly trained welders, temperamental steel compositions and various material shortages, with specifications remaining as rigid as ever, combine to make the work of the welding supervisor or engineer more troublesome than ever.

What causes cracks in welds? What factors result in conditions that favor weld cracking? What, if any, are the means of preventing cracks from occurring? In considering these questions we must remember that welding usually involves greater and more violent changes of temperature than other fabricating processes. Some of the complicated metallurgical factors involved in the welding operation are not fully understood as yet. Nevertheless, we can supply satisfactory answers to many of these questions, and the purpose of this paper is to review some of the knowledge and experience which enables us to produce satisfactory crack-free weld joints under a wide variety of conditions.

There are two areas in a welded joint which may crack as a result of the welding operation. The first is a portion of the so-called heat-affected zone adjacent to the weld. The second area which may crack under certain conditions is the weld metal itself. However, the weld metal used for most purposes has so low a carbon content that it does not change its properties as markedly as the base metal even under the most rapid rate of cooling likely to occur in welding. Therefore, the weld metal itself is less prone to cracking than the so-called heat-affected zone.

In view of this, we usually concern ourselves primarily with the base metal in the immediate vicinity of the weld. It is the metal closest to the weld that cools most rapidly, and in many cases undergoes important changes in the structure and properties that may lead to cracking.

Preheating before welding is a well-recognized preventive measure against cracking. It was used for many years before scientific reasons were advanced to explain its function in preventing cracks. The importance of preheating is shown by the fact that recommendations for preheating are written into modern welding specifications wherever there is the slightest risk of weld defect being present.

However, it is less generally recognized that preheating also contributes other useful effects. This paper will review briefly the fundamental principles involved in preheating, describe some of the beneficial effects of preheating and outline several procedures commonly used for preheating.

Preheating has been defined as "raising the temperature of metal above the temperature of the surroundings before welding." It may be added that sometimes the entire part is preheated, this being the general preheat; or, only the vicinity of the weld is heated, and this is called local preheat.

There are five principal reasons for preheating. These are listed in Table 1.

Table 1—Effects of Preheating

1. Eliminates or lessens the danger of crack formation.
2. Minimizes hard zones adjacent to weld.
3. Minimizes shrinkage stresses.
4. Lessens distortion.
5. Enhances diffusion of hydrogen from steel.

Preheating, therefore, increases the ability of a welded joint to withstand service conditions; as will be shown below, preheating may actually be viewed as a heat-treating operation.

How does preheating accomplish these beneficial results? In order to answer this question it is necessary to consider several important metallurgical principles.

The making of any weld involves two metallurgical processes: First, the melting of the edges of the joint and of the electrode material, followed by solidification which forms a single integral weld structure; second, the heating and subsequent cooling of the zone of the parent metal adjacent to the weld.

The heat generated during welding will have two

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This paper was delivered before several local Sections of the American Welding Society.

separate effects on the welded joint. Depending on metal composition, temperature reached and cooling rate there will be a specific effect on microstructure of the metal, which will in turn determine such properties as strength, toughness, ductility, shock, corrosion resistance and so forth. We will call these, perhaps somewhat arbitrarily, the metallurgical effects.

Second, heat will cause distortion and shrinkage stresses in the weld joint, this being dependent on the shape and geometry of the joint, the degree of restraint, heating and cooling rates and time at maximum temperature. We will call these the mechanical effects. Actually these two effects occur simultaneously and are interdependent, but they are separated in this discussion for convenience and simpler understanding. The welded joint, although actually a single integral structure, may be considered to consist of three distinct zones which merge into one another. The three zones are: The weld metal, the heat-affected zone and the plate material, sometimes called the base metal.

Figure 1, which is a macrograph of a single pass butt-weld joining two plates 1 in. thick, shows these three zones. The weld metal *A* is that portion which has been in molten state and consists of a mixture of the electrode material which has been deposited and plate material which has been melted during welding.

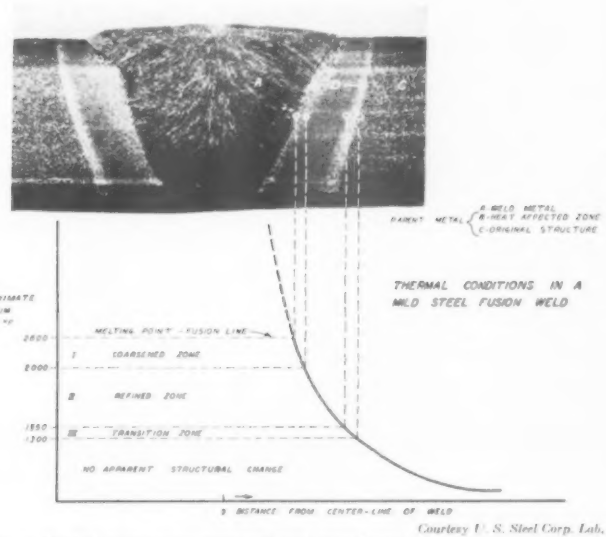
The heat-affected zone, shown as *B* is that area which, although not melted during the welding operation, has been heated to temperatures sufficiently high to change its original microstructure and properties. This zone consists of a sequence of several distinctly different structures whose precise character and extent depend upon the conditions of welding. The plate material *C* is the area that has not been affected by the weld thermal cycle. The diagram below the photograph indicates the approximate maximum temperatures reached in each zone while the weld was being made. The temperatures and structures shown indicate that the thermal cycle of the welding operation subjects the metal to a heat treatment which considerably alters its structure and properties. In order to understand the nature of the changes introduced into steel by heating and cooling cycles, one must consider the iron-carbon diagram.

The iron-carbon diagram is a summary of the physical changes which occur in steels and cast irons when the temperature is varied. Figure 2 shows a portion of the iron-carbon diagram with some additional useful metallurgical and fabricating information superimposed on it.

This diagram illustrates the effects on steel structures of temperature changes that accompany the welding operation. Typical welding grade of steel, 0.25% carbon for example, if heated to a temperature above 1525° F. becomes a solid solution of carbon in iron which has a face centered crystal structure, called austenite. On slow cooling the austenite remains unchanged until the temperature of about 1500° F. is reached. At this point austenite begins to break down and form a new phase. This new phase is almost pure iron with a body centered structure and it is called ferrite. This process continues until the temperature of 1350° F. is reached. At 1350° F. the remaining austenite transforms to still another phase called pearlite. Thus on slow cooling to room temperature steel will be composed of a ferrite-pearlite structure. This structure is soft and ductile. However, the cooling rates in welds are as a rule not slow but quite rapid. Drastic cooling of steel results in formation of a hard and brittle structure called martensite. Thus, instead of soft and ductile pearlite we get hard martensite, which due to its low ductility has poor ability to withstand welding stresses. It is the formation of this brittle structure in the base metal that causes much weld cracking.

This metallurgical knowledge helps to interpret some of the typical structures that may be found in the heat-affected zones of a welded joint. These are shown in Fig. 3

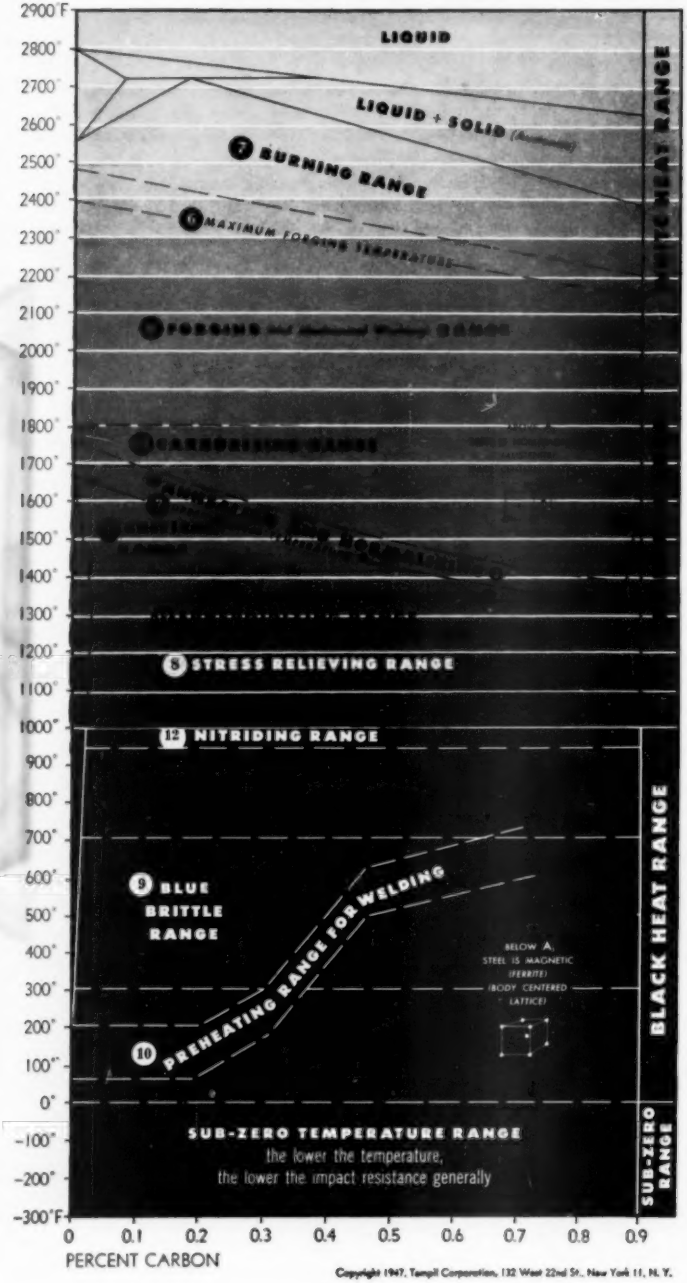
It is apparent that Zone 1 has been coarsened by the welding process and consists of a needlelike martensitic structure; Zone 2 has been refined by the heat incident to the welding operation and Zone 3 is a transition zone. Figure 3 also shows the typical normalized structure of the original unaffected parent metal.



Courtesy U. S. Steel Corp. Lab.

Fig. 1—Typical macrostructures and maximum attained temperatures in a butt weld

Basic Guide to Ferrous Metallurgy



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1 CRITICAL RANGE. In this range steels undergo internal atomic changes which radically affect the properties of the material.

2 LOWER CRITICAL TEMPERATURE (A_1). Termed Ac_1 on heating, Ar_1 on cooling. Below Ac_1 structure ordinarily consists of FERRITE and PEARLITE (See 14 and 17 below). On heating through Ac_1, the solid FERRITE and the solid PEARLITE begin to dissolve in each other to form AUSTENITE (see 15 below) which is non-magnetic. This dissolving action continues on heating thru the CRITICAL RANGE until the solid solution is complete at the upper critical temperature.

3 UPPER CRITICAL TEMPERATURE (A_3). Termed Ac_3 on heating, Ar_3 on cooling. Above this temperature the structure consists of AUSTENITE which coarsens with increasing time and temperature. Upper critical temperature is lowered as carbon increases to 0.85% (eutectoid point).

4 ANNEALING consists of heating steels to slightly above Ac_3, holding for AUSTENITE to form, then *slowly* cooling in order to produce small grain size, softness, good ductility and other properties. On cooling slowly the AUSTENITE transforms to FERRITE and PEARLITE.

5 NORMALIZING is similar to annealing except that cooling is done *in still air*. On cooling, AUSTENITE transforms giving somewhat higher strength and hardness and slightly less ductility than in annealing.

6 FORGING RANGE extends to several hundred degrees above the UPPER CRITICAL TEMPERATURE.

7 BURNING RANGE is above the FORGING RANGE. BURNED steel *cannot be cured* except by remelting.

8 STRESS RELIEVING consists of heating to a range definitely below the LOWER CRITICAL TEMPERATURE, holding for one hour or more per inch of thickness, then slowly cooling. Purpose is to allow the steel to relieve itself of locked-up stresses.

9 BLUE BRITTLE RANGE occurs approximately at 300° to 700°F., in which range steels are more brittle than above or below this range. Peening or working of steel should not be done in this range.

10 PREHEATING FOR WELDING is carried out to prevent crack formation. See TEMPIL® PREHEATING CHART for recommended temperatures for various steels and non-ferrous metals.

11 CARBURIZING consists of dissolving carbon into surface of steel by heating to above critical range in presence of carburizing compounds.

12 NITRIDING consists of heating certain *special steels* to about 1000°F. for long periods in the presence of ammonia gas. Nitrogen is absorbed into the surface to produce extremely hard "skins."

13 SPHEROIDIZING consists of heating to just below the critical range to put the CEMENTITE constituent of PEARLITE in globular form. This produces softness and in many cases good machinability.

FERRITE is practically pure iron (in plain carbon steels) existing below the lower critical temperature. It is magnetic and has very slight solid solubility for carbon.

AUSTENITE is the non-magnetic form of iron and has the power to dissolve carbon and alloying elements.

CEMENTITE or IRON CARBIDE is a chemical compound of iron and carbon, Fe_3C.

PEARLITE is a mechanical mixture of FERRITE and CEMENTITE.

EUTECTOID STEEL contains approximately 0.85% carbon.

MARTENSITE is an extremely hard constituent of steels; formed by the rapid transformation of AUSTENITE.

FLAKING occurs in many alloy steels and is a defect characterized by localized micro-cracking and "flake-like" fracturing. It is usually attributed to hydrogen burns. Cure consists of cycle cooling to at least 600°F. before air-cooling.

OPEN OR RIMMING STEEL is not completely deoxidized and the ingot solidifies with blowholes.

KILLED STEEL has been deoxidized at least sufficiently to solidify without appreciable gas evolution.

A SIMPLE RULE: Brinell Hardness divided by two, times 1000, equals approximate Tensile Strength in pounds per square inch. *(200 Brinell ÷ 2 x 1000 = approx. 100,000 Tensile Strength, p.s.i.)*

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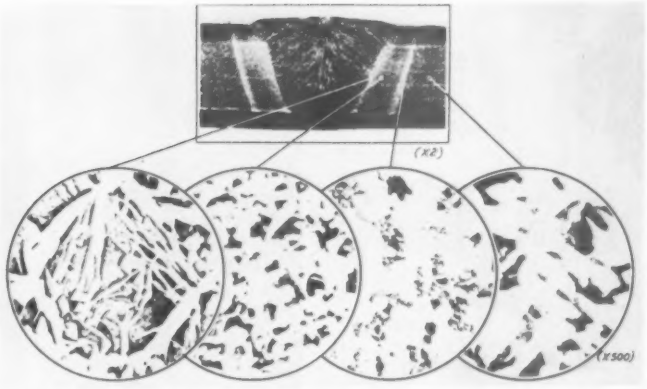
Fig. 2



Courtesy U. S. Steel Corp. Lab.

Fig. 3—Typical microstructures in the heat-affected zone of a butt weld

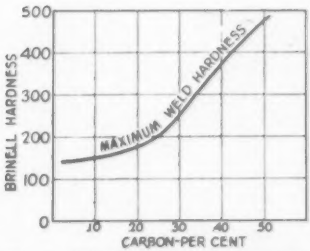
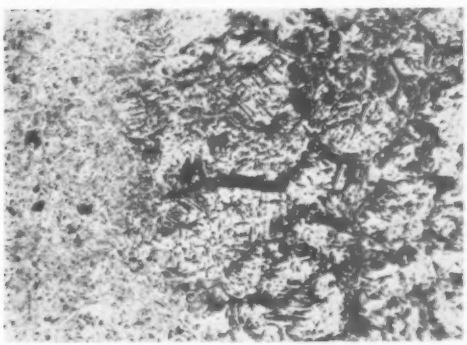


Fig. 5 Effect of carbon content in plain carbon steels after weld hardening procedure

The principal danger of cracking is found in Zone 1 which consists principally of coarsened martensite. Figure 4 shows this structure under higher magnification. The brittle martensite present gave rise to a crack which in all probability, will eventually extend further under the influence of welding stresses.

The factors just described comprise the metallurgical effects of the welding operation. The mechanical effects of the heating and cooling cycles during welding result in sudden and highly nonuniform expansion and contraction. These will set up stresses that cause the welded joint to deform continually during and after the welding cycle. In general a metal will crack if stresses exceed its ability to deform. Thus a weld joint composed of a material which possesses sufficient ductility—such as ferrite and pearlite—will deform without cracking while a weld which contains a brittle structure such as martensite may react to thermal stresses by cracking. This illustrates the interdependence of metallurgical and mechanical considerations stated previously.



Courtesy Lehigh University

Fig. 4—Initial crack in hardened portion of the heat affected zone of the weld

With this background, the five factors which determine the ability of steel to be welded without cracking can be listed as follows:

Table 2

1. Composition of steel.
2. Rate of heating.
3. Maximum temperature attained and length of time at temperature.
4. Rate of cooling.
5. Hydrogen entrapment.

The chemical composition of steel has a very important bearing on the hardness and brittleness of the weld joint for several reasons: First, because higher carbon content promotes the formation of martensite, and second, because the final hardness or martensite itself depends on the carbon content of steel. The effect of carbon content on hardness of steel subjected to welding is shown in Fig. 5. This, of course, is the reason why steels of higher carbon analysis are not considered easily weldable. Certain alloying elements such as molybdenum, manganese, vanadium and chromium also have a distinct hardening effect, promoting the formation of the crack-inducting martensite. The relative hardening influence of the important alloying elements is indicated in Fig. 6. Thus the higher the carbon and alloy content of steel the more readily it will harden in the heated zone, and therefore the slower the cooling rate will have to be in order to prevent cracking.

The next three factors in Table 2 are of thermal nature. The great and violent changes in temperature involved in welding can be illustrated by temperature changes of a point in the heat-affected zone of a weld. Such a typical time-temperature curve is shown in Fig. 7. Within the first second after welding this point rapidly reaches a very high temperature of approximately 2450° F., and then drops in the next few seconds to temperatures below 500° F.

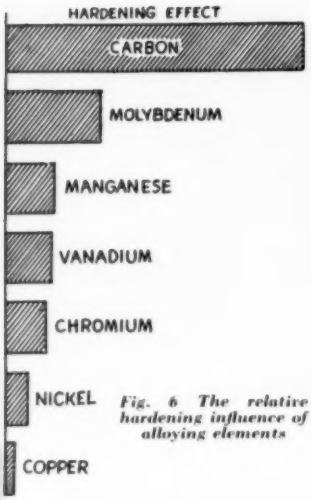


Fig. 6 The relative hardening influence of alloying elements

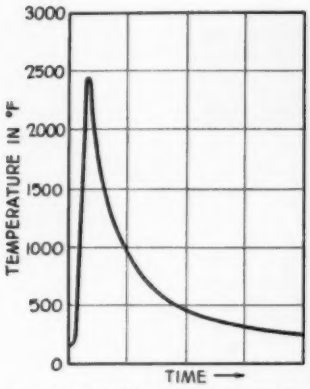


Fig 7 Typical time-temperature curve for a point in the heat-affected zone of a weld

Courtesy Air Reduction Sales Co.

Fig. 8 Temporary firebrick charcoal fired furnace for preheat of castings

The rate of heating is important for two reasons. First, because rapid heating may result in high thermal stresses, and second, because rapid heating will cause a high cooling rate thus promoting the formation of brittle martensite. The rate of heating will determine the steepness of the rising portion of the curve in Fig. 7 and it will vary with the welding process or, more specifically, with the method used for generating heat at weld joint—electric arc, oxyacetylene, heliarc and so on. For example, the electric arc provides a faster rate of heating than the oxyacetylene because the arc is a more intense heat source, and is in more intimate contact with the metal. The maximum temperature and the time at temperature are important because they determine the amount of austenite that will be formed and thus the amount of change in microstructure which will take place.

The maximum temperature attained and the time at temperature besides being influenced by the welding process employed are also dependent on other factors such as the time and speed of welding, arc current, arc voltage and the welding sequence. In other words, the maximum temperature reached depends upon the heat input of a welding rod. A $^1/_8$-in. diameter electrode used at 400 amp. and 40 v. will result in higher maximum temperature of a joint in the heat-affected zone than a $^1/_8$-in. electrode used with 150 amp. and 20 v. A higher temperature will also be obtained at any location in the heat-affected zone if the speed of travel were 6 in. per minute instead of 12 in. per minute, other factors being equal. The use of string bead or weave technique, the number of layers and the time between succeeding weld beads all play an important part in determining the maximum temperature attained.

Of the five factors in Table 2 the rate of cooling has the greatest influence on the structures of the heat-affected zone. As shown previously the cooling rate will determine the final structures of the transformation products which result from the welding operation. If austenite is cooled slowly the transformation products will be soft and ductile. If the transformation from austenite is rapid, the final products will be brittle and may crack if stressed. As welding is a quick process, the cooling rates are quite rapid and the portions of the heat-affected zone are likely to consist of this brittle constituent. Thus the cooling rate determines the hardness and brittleness in the heat-affected zone and by controlling the cooling rate it is possible to create welding conditions which will prevent this brittle structure from forming, and thus prevent cracks. The rate of cooling is dependent on the mass and geometry of the piece to be welded, the temperature gradient between the weld joint and the base metal and the total heat input.

Some authorities believe that cracks in welds are due to hydrogen introduced into the base metal from the coatings of welding rods. As hydrogen is more soluble in molten than in solid steel, it will seek to escape from the supersaturated solution as metal cools down to room temperature. If the escaping hydrogen is trapped within a discontinuity in the metal, and if such entrapment occurs within a hardened area, cracking may result.

Two practices are commonly utilized to prevent the formation of cracks in welded joints: Preheating and postheating. Preheating is used to prevent cracks during and immediately after the welding operation, and postheating to insure crack-free welds before the metal enters service and also to insure satisfactory metallurgical properties to withstand service conditions. Preheating acts to prevent cracks in several ways. First, it reduces the thermal gradient between base and weld metals. For example, a drop of

only 2000° F. occurs if a weld is preheated to 800° F. as compared with the 2730° drop from 2800° to 70° F. for a weld made at room temperature. This reduces the cooling rate preventing the formation of brittle martensite and causing metallurgical transformations to take place that produce softer and more ductile constituents. Thus preheating reduces the hardness of the heat-affected zone and the tendency to cracking.

As steel is less heat conductive at higher temperatures, preheating causes slower withdrawal of heat from the welded joint. This further lowers the cooling rate with correspondingly beneficial effects.

Preheating has been found to be helpful in eliminating hydrogen entrapment in the base material. Many fabricating procedures recommend preheating even in conjunction with the low-hydrogen type electrodes. Although the arc atmospheres of the so-called hydrogen-free electrodes contain very small amounts of hydrogen—even traces of this element are sometimes sufficient to cause cracking in the embrittled heat-affected zone.

The useful effects of preheating can be summarized as follows: Hard martensitic zones occur in weld joints as a result of rapid cooling rates. These hard zones are likely to crack during or after the welding operation. The shrinkage stresses due to cooling augmented by the volume changes of steel during phase transitions may exceed the capacity of the hard zone to deform and thereby crack it. This may be aided by the presence of hydrogen which has an embrittling effect on steel. Preheating prevents weld cracking in three ways: It minimizes the formation of the brittle martensite, it causes austenite to transform very slowly to martensite and it increases the diffusion and escape rate of hydrogen.

The foregoing is summarized in practical terms in Table 3 as the eleven factors which increase the need for preheating.

Table 3

Preheating Need Is Increased If the Welded Piece

1. Has larger mass.
2. Is at lower temperature.
3. Is in an environment of lower temperature.
4. Is welded with smaller rod diameter.
5. Is welded at greater linear speed.
6. Has complicated shape and design.
7. Has large variation in size of adjacent parts.
8. Has higher carbon content.
9. Has higher manganese content.
10. Has higher alloy content.
11. Has greater air-hardening capacity.

A chart which summarizes recommended preheat temperatures for 79 commonly used metal and alloys is shown in Table 4.

Preheating is usually accomplished by various methods. The most popular ones involves the use of gas torches, various other types of burners, regular heat-treating furnaces, electrical strip heaters, low-frequency induction heating and firebrick furnaces

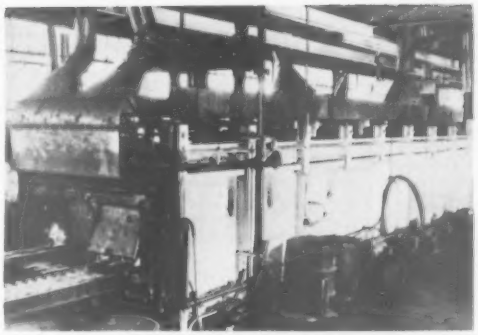


Fig. 9 Continuous annealing furnaces used for preheat of castings

utilizing charcoal or coke as fuel. The choice of a particular method depends, of course, on many factors such as the preheating temperature and length of preheating time required, size and shape of piece being welded, whether production is of a batch or continuous type and so forth. A typical firebrick furnace construction which utilizes charcoal or coke as fuel is shown in Fig. 8. This type of furnace is popular for temporary work as it can be readily erected and, if necessary, easily dismantled. In many shops regular heat-treating furnaces, such as shown in Fig. 9, are utilized for preheating. These are particularly advantageous in mass production work, and are sometimes combined with the other methods of preheating in order to save labor and fuel. For example, the castings preheated in continuous annealing furnaces shown in Fig. 9 are removed to the casting repair area where specially shaped multiple jet heating torches (Fig. 10) are used to maintain preheat temperatures attained in furnaces.

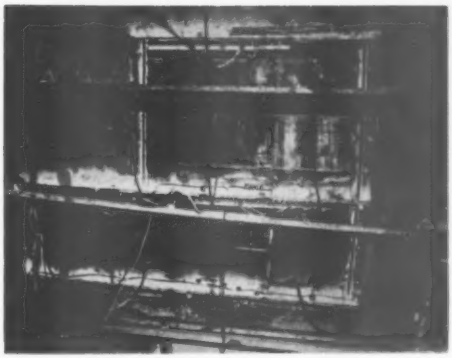
In heavy fabrication like shipbuilding and the manufacture of large pressure vessels which require continuous application of preheat, a popular method utilizes electrical strip heaters, shown in Fig. 11.

Courtesy "The Welding Engineer"

Fig. 10 Preheat imparted by continuous furnaces is maintained by means of gas torches and asbestos blankets

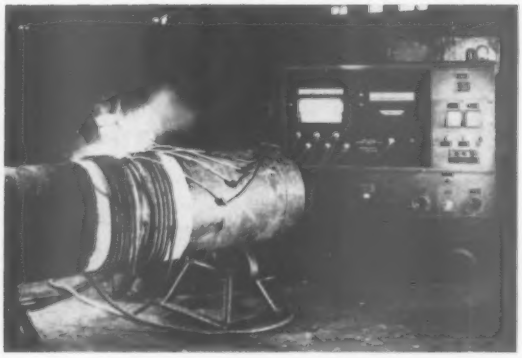
Table 4—Preheat Temperatures for Metals and Alloys

METAL GROUP	METAL DESIGNATION	APPROXIMATE COMPOSITION — PERCENT								METAL DESIGNATION	RECOMMENDED PREHEAT
		C.	Mn.	Si.	Cr.	Ni.	Mo.	Cu.			
PLAIN CARBON STEELS	PLAIN CARBON STEEL	BELOW .20								PLAIN CARBON STEEL	UP TO 200°F
	PLAIN CARBON STEEL	.20-.30								PLAIN CARBON STEEL	200°F-300°F
	PLAIN CARBON STEEL	.30-.45								PLAIN CARBON STEEL	300°F-500°F
	PLAIN CARBON STEEL	.45-.80								PLAIN CARBON STEEL	500°F-800°F
CARBON MOLY STEELS	CARBON MOLY STEEL	.10-.20					.50			CARBON MOLY STEEL	300°F-500°F
	CARBON MOLY STEEL	.20-.30					.50			CARBON MOLY STEEL	400°F-600°F
	CARBON MOLY STEEL	.30-.35					.50			CARBON MOLY STEEL	500°F-800°F
MANGANESE STEELS	SILICON STRUCTURAL STEEL	.35	.80	.25						SILICON STRUCTURAL STEEL	300°F-500°F
	MEDIUM MANGANESE STEEL	.20-.25	1.0-1.75							MEDIUM MANGANESE STEEL	300°F-500°F
	SAE T 1330 STEEL	.30	1.75							SAE T 1330 STEEL	400°F-600°F
	SAE T 1340 STEEL	.40	1.75							SAE T 1340 STEEL	500°F-800°F
	SAE T 1350 STEEL	.50	1.75							SAE T 1350 STEEL	600°F-900°F
	12% MANGANESE STEEL	1.25	12.0							12% MANGANESE STEEL	USUALLY NOT REQUIRED
HIGH TENSILE STEELS (SEE ALSO STEELS BELOW)	MANGANESE MOLY STEEL	.20	1.65	.20			.35			MANGANESE MOLY STEEL	300°F-500°F
	JALTEN STEEL	.35 MAX.	1.50	.30				.40		JALTEN STEEL	400°F-600°F
	MANTEN STEEL	.30 MAX.	1.35	.30				.20		MANTEN STEEL	400°F-600°F
	ARMCO HIGH TENSILE STEEL	.12 MAX.				.50 MIN.	.05 MIN.	.35 MIN.		ARMCO HIGH TENSILE STEEL	UP TO 200°F
	DOUBLE STRENGTH #1 STEEL	.12 MAX.	.75			.50-1.25	.10 MIN.	.50-1.50		DOUBLE STRENGTH #1 STEEL	300°F-600°F
	DOUBLE STRENGTH #1A STEEL	.30 MAX.	.75			.50-1.25	.10 MIN.	.50-1.50		DOUBLE STRENGTH #1A STEEL	400°F-700°F
	MAYARI R STEEL	.12 MAX.	.75	.35	.3-1.0	.25-.75		.60		MAYARI R STEEL	UP TO 300°F
	OTISCOLOY STEEL	.12 MAX.	1.25	.10 MAX.	.10 MAX.			.50 MAX.		OTISCOLOY STEEL	200°F-400°F
	NAX HIGH TENSILE STEEL	.15-.25		.75	.60	.17	.15 MAX.	.25 MAX.	Zr. .12	NAX HIGH TENSILE STEEL	UP TO 300°F
	CROMANSIL STEEL	.14 MAX.	1.25	.75	.80					CROMANSIL STEEL	300°F-400°F
	A. W. DYN-EL STEEL	.11-.14						.40		A. W. DYN-EL STEEL	UP TO 300°F
	CORTEN STEEL	.12 MAX.		.25-1.0	.5-1.5	.55 MAX.		.40		CORTEN STEEL	200°F-400°F
	CHROME COPPER NICKEL STEEL	.12 MAX.	.75		.75	.75		.55		CHROME COPPER NICKEL STEEL	200°F-400°F
	CHROME MANGANESE STEEL	.40	.90		.40					CHROME MANGANESE STEEL	400°F-600°F
	YOLOY STEEL	.06-.35	.3-1.0			1.75		1.0		YOLOY STEEL	200°F-600°F
	HI-STEEL	.12 MAX.	.6	3 MAX.		.55		.9-1.25		HI-STEEL	200°F-500°F
NICKEL STEELS	SAE 2015 STEEL	.10-.20				.50				SAE 2015 STEEL	UP TO 300°F
	SAE 2115 STEEL	.10-.20				1.50				SAE 2115 STEEL	200°F-300°F
	2½% NICKEL STEEL	.10-.20				2.50				2½% NICKEL STEEL	200°F-400°F
	SAE 2315 STEEL	.15				3.50				SAE 2315 STEEL	200°F-500°F
	SAE 2320 STEEL	.20				3.50				SAE 2320 STEEL	200°F-500°F
	SAE 2330 STEEL	.30				3.50				SAE 2330 STEEL	300°F-600°F
	SAE 2340 STEEL	.40				3.50				SAE 2340 STEEL	400°F-700°F
MEDIUM NICKEL CHROMIUM STEELS	SAE 3115 STEEL	.15			.60	1.25				SAE 3115 STEEL	200°F-400°F
	SAE 3125 STEEL	.25			.60	1.25				SAE 3125 STEEL	300°F-500°F
	SAE 3130 STEEL	.30			.60	1.25				SAE 3130 STEEL	400°F-700°F
	SAE 3140 STEEL	.40			.60	1.25				SAE 3140 STEEL	500°F-800°F
	SAE 3150 STEEL	.50			.60	1.25				SAE 3150 STEEL	600°F-900°F
	SAE 3215 STEEL	.15			1.00	1.75				SAE 3215 STEEL	300°F-500°F
	SAE 3230 STEEL	.30			1.00	1.75				SAE 3230 STEEL	500°F-700°F
	SAE 3240 STEEL	.40			1.00	1.75				SAE 3240 STEEL	700°F-1000°F
	SAE 3250 STEEL	.50			1.00	1.75				SAE 3250 STEEL	900°F-1100°F
	SAE 3315 STEEL	.15			1.50	3.50				SAE 3315 STEEL	500°F-700°F
	SAE 3325 STEEL	.25			1.50	3.50				SAE 3325 STEEL	900°F-1100°F
	SAE 3435 STEEL	.35			.75	3.00				SAE 3435 STEEL	900°F-1100°F
	SAE 3450 STEEL	.50			.75	3.00				SAE 3450 STEEL	900°F-1100°F
MOLY BEARING CHROMIUM AND CHROMIUM NICKEL STEELS	SAE 4140 STEEL	.40			.95		.20			SAE 4140 STEEL	600°F-800°F
	SAE 4340 STEEL	.40			.65	1.75	.35			SAE 4340 STEEL	700°F-900°F
	SAE 4615 STEEL	.15				1.80	.25			SAE 4615 STEEL	400°F-600°F
	SAE 4630 STEEL	.30				1.80	.25			SAE 4630 STEEL	500°F-700°F
	SAE 4640 STEEL	.40				1.80	.25			SAE 4640 STEEL	600°F-800°F
	SAE 4820 STEEL	.20				3.50	.25			SAE 4820 STEEL	600°F-800°F
LOW CHROME MOLY STEELS	2% Cr.-½% Mo. STEEL	UP TO .15			2.0		0.5			2% Cr.-½% Mo. STEEL	400°F-600°F
	2% Cr.-½% Mo. STEEL	.15-.25			2.0		0.5			2% Cr.-½% Mo. STEEL	500°F-800°F
	2% Cr.-1% Mo. STEEL	UP TO .15			2.0		1.0			2% Cr. 1% Mo. STEEL	500°F-700°F
	2% Cr.-1% Mo. STEEL	.15-.25			2.0		1.0			2% Cr. 1% Mo. STEEL	600°F-800°F
MEDIUM CHROME MOLY STEELS	5% Cr.-½% Mo. STEEL	UP TO .15			5.0		0.5			5% Cr.-½% Mo. STEEL	500°F-800°F
	5% Cr.-½% Mo. STEEL	.15-.25			5.0		0.5			5% Cr.-½% Mo. STEEL	600°F-900°F
	8% Cr.-1% Mo. STEEL	.15 MAX.			8.0		1.0			8% Cr.-1% Mo. STEEL	600°F-900°F
PLAIN HIGH CHROMIUM STEELS	12-14% Cr. TYPE 410	.10			13.0					12-14% Cr. TYPE 410	300°F-500°F
	16-18% Cr. TYPE 430	.10			17.0					16-18% Cr. TYPE 430	300°F-500°F
	23-30% Cr. TYPE 446	.10			26.0					23-30% Cr. TYPE 446	300°F-500°F
HIGH CHROME NICKEL STAINLESS STEELS	18% Cr. 8% Ni. TYPE 304	.07			18.0	8.0				18% Cr. 8% Ni. TYPE 304	USUALLY DO NOT REQUIRE PREHEAT BUT IT MAY BE DESIRABLE TO REMOVE CHILL
	25-12 TYPE 309	.07			25.0	12.0				25-12 TYPE 309	
	25-20 TYPE 310	.10			25.0	20.0				25-20 TYPE 310	
	18-8 Cb. TYPE 347	.07			18.0	8.0			Cb. 10XC	18-8 Cb. TYPE 347	
	18-8 Mo. TYPE 316	.07			18.0	8.0	2.5			18-8 Mo. TYPE 316	
	18-8 Mo. TYPE 317	.07			18.0	8.0	3.5			18-8 Mo. TYPE 317	



Courtesy the Newport News Shipbuilding & Dry Dock Co.

Fig. 11 Electrical strip heaters in place on a typical shell repair



Courtesy "The Welding Engineer"

Fig. 12 Preheating by induction during welding

Another widely employed method utilizes low-frequency induction heating and is particularly useful where close temperature control is required. Figure 12 shows the use of induction heating in preheating of alloy steel piping prior to welding.

Preheating before welding is now widely accepted as a desirable fabricating procedure. Both ferrous and nonferrous metal producers state recommended preheating temperatures for welding their materials. Prescribed preheating temperatures and procedures are today included in the majority of fabricating specifications. While preheating methods and temperatures will depend on many factors like metal composition and mass, fabricating methods and service conditions, there is unanimous agreement that preheating before welding is the best possible insurance against cracks.

Bibliography

1. Davenport, E. S., and Aborn, R. H., "Metallurgical Aspects of the Welding of Steel," THE WELDING JOURNAL, **15** (10), 21–31 (1936).
2. Aborn, R. H., "Metallurgical Changes at Welded Joints and the Weldability of Steels," *Ibid.*, **19** (10), 414-s to 426-s (1940).
3. Lloyd, T. E., "Black Heat Temperatures," *The Iron Age*, (July 24, 1941).
4. Lawrence, Harold, "Weldability," *Steel*, (Jan. 26, 1942).
5. Lawrence, Harold, *Welding Substitute Steels, Ibid.* (Aug. 31, 1942).
6. Henry, O. H., and Claussen, G. A., "Welding Metallurgy," Revised by G. E. Linnert.
7. "How to Build a Charcoal Preheating Furnace," *The Welding Engineer*, 50–51 (October 1946).
8. Seabloom, Eric R., "Welding Methods for Alloy-Steel Piping," *Ibid.*, (September-November 1946).
9. Bledsoe, L. F., "Repair of Welded Ships," THE WELDING JOURNAL, **27** (9) 690–694 (1948).
10. Rex, R. L., "Diesel Locomotive Maintenance," *Ibid.*, **27** (12), 1034–1042 (1948).
11. Blake, A. E., Jr., "How We Repair Steel Castings," *The Welding Engineer*, 26–29 & 33 (April 1951).
12. Stout, R. D., "Metallurgy of Arc Welding in Steel," THE WELDING JOURNAL, **28** (4), 335–352 (1949).
13. Rankin, A. W., and Clark, R. W., "Design and Fabrication of Steam Piping," THE WELDING JOURNAL, **30** (6), 508–522 (1951).
14. "Recommended Practices for Salvaging Automotive Gray Iron Castings by Welding," AMERICAN WELDING SOCIETY, 1950.

Should Welding Be on Its Own in Education?

Discussion by Donald S. Clark

There should be no question about welding being an important process in the field of engineering. It can be in many instances a means of fabrication or repair which is more economical and better for strength than some other methods. The design engineer must be conversant with what can be done by welding and with welding in relation to the strength of welded structures. One should bear in mind that there are many different methods of fabrication, each of which has its advantages and limitations.

What do we as educators expect to accomplish in four years of undergraduate training in the engineering college? What does industry expect of the engineering graduate as he leaves the college and enters employment? The answer to the first question depends in

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part on the answer to the second question. As far as I have been able to determine, by discussing this question with industrial representatives in my capacity as Director of Placements, they want men from engineering colleges who are mentally flexible, who have had their thinking power developed, who have developed their power of vision and leadership, and who have learned the fundamentals of science that form the foundation of engineering. Industry wants engineers who are live men and who can engage in cooperative efforts with a minimum of personality conflicts. These should be the objectives of engineering education. To accomplish them there must be a proper balance between the basic sciences, analytical engineering courses, laboratory courses, and the humanities. It is apparent that more and more of the engineering colleges are tending toward this broader form of training.

How many students know, when they enter an engineering college, that they wish to become specialists in fields such as welding? Most of them are not certain as to which of the broad fields of engineering they may wish to pursue. A large number of students do not formulate any specific notion of specialization by the time they are seniors and this is probably a healthy condition. A man cannot determine if he will be successful in some specific phase of the all-inclusive profession of engineering until he has had an opportunity of being intimately associated with that phase under actual working conditions. This cannot be done by the engineering colleges. Practice is secured most effectively through industrial employment.

Integration of fundamental subject matter in the engineering curriculum is extremely important, but difficult to accomplish. Most educators recognize the "pigeon-holing" tendency of students when different subjects are covered over the four-year period. Methods by which this differentiation of subject matter is decreased are not simple, but some advances have been made in certain quarters. Any time a specialty course is inserted in the curriculum, the tendency toward integration is decreased. This is what happens when a special course in welding is introduced. If this course is to contain such material as processes, techniques, testing, metallurgy, and design in welding, then specialty courses should be established to cover in detail casting, forging, cold forming, etc. This we should *not* do. All of these processes should be considered together. They should be introduced in early courses in engineering materials and processes and later in courses in design and engineering metallurgy.

The reticence of the engineering colleges to include special subjects or courses in welding is not, as Prof. Wiley states, a question of losing students to newer fields and loss of prestige. We, as educators, are concerned with teaching young men the things which will assist them to grasp opportunity and to enjoy living as a part of a free society. We should not be concerned whether we are civil, electrical, aeronautical, chemical, or mechanical engineers; we are all engineers with different capacities and different likes and dislikes. Naturally we like best those who enjoy the same things we do. We balk at specialized courses, because we believe such early specialization at the sacrifice of fundamentals, is not to the students' long-range benefit.

It is well known that a large number of men who graduate in engineering are engaged in quite different types of work ten years after graduation than when they started out in their engineering career. We must leave our graduates flexible, and this can be done only by directing our attention to fundamentals and such integrated practices as are necessary in engineering.

The teaching of technicians is a different matter. In this case, a man is trained to carry on a specific operation. Therefore, he must be directed into that specialty. Certainly we need technicians and they must be trained, but we also need forward thinking engineers who will not carry on only by "rule of thumb," but will utilize their developed analytical ability.

Industries can help in the education of our undergraduates. They can help the student in his problem of orientation. They can help the student to visualize some of the practical applications of his college work. They can also benefit themselves by carefully looking over the field of young men who will be seeking full-time employment. This help can be given by summer work and training programs. This of course is a problem, but a solution can be found to the benefit of all.

In conclusion, I believe that Prof. Wiley's article should stimulate some thought by engineering educators even though I think his approach to the problem is incorrect. It is probably true that there are some in engineering education who are behind the times. Let us get the fundamentals of welding into our undergraduate engineering curriculum by integration, not by differentiation.

Recommended Practice for the Welding of Steel Castings

Excerpt-Report of an exhaustive study of welding practices for the welding of steel castings

Foreword

The report which follows is based on exhaustive studies on recommended practices for the welding of steel castings carried out as part of the continuing research and development program of Steel Founders' Society of America.

The result of this specific research project is a handy and valuable reference manual constituting a reliable basis for quality welding of steel castings and a completely dependable guide for steel foundrymen and all industry to use in establishing acceptable welding procedures.

While welding on occasion assumes importance comparable to molding, coring, melting and pouring or other operations incidental to steel casting manufacture, the manual likewise recognizes realistically that industry also is engaged in welding steel castings together ("Cast-Weld Construction," THE WELDING JOURNAL, 30 (5) 415 to 423 (1951)) and in fabricating structures through the welding of steel castings to wrought steel products (composite fabrication).

The experience-proved procedures outlined here, and concerned primarily with welding methods, thus are equally adaptable to the needs and problems of the fabricator as well as the foundry. In short, all steel is weldable—whether wrought or cast—but some steels are not as readily weldable as others, unless certain precautions requiring special operational techniques are employed. While these techniques were generally known and used by the steel casting industry, there previously has been no single source reference to which an operating man could turn for a restatement or summary of the details of these established techniques. The Steel Founders' Society manual fulfills that need with thoroughness and great practical utility, and this excerpt-report covers the highlights of such recommended practices incorporated in detail in the 40-page manual.

INTRODUCTION

WELDING is an important part of the manufacturing of steel castings. It is used in two ways—for the repair of defects incident to the manufacture of castings, and in the fabrication of composite structures. This report deals only with the welding of steel castings by the metal-arc method.

Arc-welding procedures in the foundry are a result of many years of experience, and are in line with accepted welding practice. However, the increase in variety of castings manufactured, and of electrodes available, has made it necessary to revise some of the procedures. To do this, experience with wrought steels (where welding has been used far more extensively) has been drawn upon. Steel castings can be welded as readily as wrought steels, so that the extensive information gathered on wrought steels can be applied to the welding of steel castings.

In some ways, welding of castings is simpler than welding wrought steels, because, with relatively few exceptions, all castings welded are subsequently stress relieved, or given a full heat treatment (e.g., normalized, or quenched and tempered). This eliminates two of the principal drawbacks found in some welded wrought steels—excessive hardness next to the weld, and severe weld stresses.

The primary objective of this report is to recommend procedures which will lead to sound, crack-free welds. With the many possible combinations of castings and electrodes, it is recognized that there may be other welding procedures equally as satisfactory as those recommended. Also, there are times when it is neither necessary nor economical to make welds of the highest quality. Such exceptions will not be considered in this report. They have to be made on the spot, for a particular job.

Specifications for Welding Castings

It is not an objective of this report to discuss in any detail the various specifications for the welding of steel castings. There are four general types of such specifications: issued by government agencies, such as the Navy, Army and Air Force; by technical societies, such as the AMERICAN WELDING SOCIETY, American Society for Testing Materials and the Association of American Railroads; by various foundries, for governing welding procedures in their own plants; and by industrial customers of the foundries. In many cases, particularly in government specifications, the welding procedures are merely a part of a broader specification for some one type of casting. This is also true of some of the technical society specifications.

A number of the government and technical society specifications have been reviewed for the purpose of checking the procedures recommended in this report

against the procedures required by the various specifications. Generally, the specified procedures are less concise than the present recommended procedures, so that good comparisons were not possible. The specifications which have been reviewed are listed in Table 1.

Table 1—List of Applicable Specifications Reviewed for This Report

U. S. Navy

General specifications for inspection of material:
Appendix II Metals, Part F—Radiography, Section F-1—Definitions and Radiographic Requirements.
Appendix VII Welding, Part C, Section C-3—The Welding of Cast Steels.
46E2—Electrodes, Welding (Covered), Molybdenum Alloy Steel.
46S5—Steel, Alloy (Special), Castings (Aircraft Use).
47E3—Electrodes, Welding (Covered or Bare), Iron and Steel.

U. S. Army

AX-1166—Steel Castings, Special.

Federal

QQS-681b—Federal Specification for Steel: Castings.

Military

MIL-E-986 (Ships)—Electrodes (Mineral Covered, Low Hydrogen), Welding, Medium and Alloy Steels.
MIL-S-870 (Ships)—Steel, Molybdenum Alloy, Castings.
MIL-S-15083 (Ships)—Steel, Castings.

American Society for Testing Materials

A27–46T Mild to Medium Strength Carbon-Steel Castings for General Application.
A95–44 Carbon-Steel Castings for Valves, Flanges and Fittings for High-Temperature Service.
A148–46T High-Strength Steel Castings for Structural Purposes.
A157–44 Alloy-Steel Castings for Valves, Flanges and Fittings for High-Temperature Service.
A216–47T Carbon-Steel Castings Suitable for Fusion Welding for High-Temperature Service.
A217–47T Alloy-Steel Castings Suitable for Fusion Welding for High-Temperature Service.
A217–49T (New Specification Superseding A157 and A217—Being Approved).

Association of American Railroads

M-201-47 Steel Castings.
M-203-48 Truck Side Frames, Cast Steel.
M-204-47 For Purchase and Acceptance of AAR Standard "E" Couplers, Knuckles, Locks and Other Parts.
M-206-47 Purchase and Acceptance of AAR Standard "H" Tight Lock Couplers and Coupler Parts, Radial Connections, Yokes and Attachment Parts.

Society of Automotive Engineers

SAE Automotive Steel Castings, Recommended Practice.

Casting Defects That Can Be Repaired by Welding

The casting defects that can be repaired by welding are well known to the foundries and have been described in the foundry literature. It is outside the scope of this report to describe these defects, or to distinguish between those which should be repaired by welding and those which should not, because of their size or location.

Some casting specifications arbitrarily classify defects into major and minor ones, according to the relative dimensions of the defects and the castings, or according to the reason for making the weld. Such classifications have not been considered in this report. Actually, welding small defects frequently requires greater care than welding large ones. This will be explained later.

PREPARATION FOR WELDING

The methods for removing defects in castings are well known to the foundry industry and need not be described in detail here. They include pressure blasting, chipping (with a pneumatic or hand chisel), grinding and flame gouging. Within reasonable limits, the first three may be done regardless of the temperature of the casting. Flame gouging, at least for the higher composition castings, must be done only when the casting is preheated. Otherwise, checks or cracks may be produced at the surface.

To properly prepare a casting for repair welding, all traces of the defect must be removed. For deep cracks this is sometimes difficult, because the method used for removing the defect may cause the metal to flow over the cracks. In such cases, careful inspection such as magnetic particle testing, deep acid etching, etc., is needed to determine whether the defect is entirely removed.

The shape of the groove made in removing a defect or preparing two castings for fabrication is also important. The dimensions of the groove are largely controlled by the size of the defect or the casting section to be welded. All changes in contour should be fairly gradual, and all sides should slope toward the bottom of the groove. Sharp inside corners serve as points of stress concentration, which might start cracks during welding. Deep, narrow grooves make it very difficult to get complete weld penetration. They promote undercutting. Incomplete penetration and undercutting may lead to slag inclusions or cavities at the roots and sidewalls of the welds. In some cases, such weld defects would require removal of the weld, recleaning of the groove surfaces and rewelding.

Sometimes, two defects may be so close to each other that one of them may not be discovered during inspection. The one that is found may be completely removed, and a clean repair groove made. Then, the repair weld may penetrate through the sound metal between the two defects, and expose the second one. When this happens, welding should be stopped and the second defect completely removed.

When defects extend entirely through a casting, it is best to turn it over and lay one or more sealing passes from the root side of the repair weld. If this cannot be done, a backing should be used wherever possible. Backings can be made from refractory materials available in the foundry, such as firebrick, silica brick, mullite brick, magnesite or carbon plates. These should be thoroughly dried, because if water vapor is produced during welding, it may cause cold cracking at the joint, as explained later. Metals, such as copper, plain-carbon steel or stainless steel, may also be used as backing material. Ordinarily, the back-up material merely acts as a dam and is not bonded to the weld metal. Such is the case with refractories and copper. Backings forming integral parts of the castings should generally have the same composition. Where pickup of backing

metal is not wanted, it is possible to cover the backings with washes of refractory materials.

EFFECTS OF WELDING

The peak temperature in metal-arc welding is highly localized, so that there is a sharp temperature gradient between the molten weld metal and the base metal only a fraction of an inch away. The rapid cooling of this weld zone by the adjacent unaffected base metal causes a wide variety of structures within this narrow zone. The structural changes involved have been described many times in the welding literature. Good descriptions are given in the *Welding Handbook* (A.W.S.),[1] and in *Welding Metallurgy* (A.W.S.).[2] The principal effects of welding castings and the subsequent rapid cooling are quench hardness, thermal stresses, hot cracks and cold cracks—i.e., cracks formed well below the critical temperature.

Quench Hardness

The rapid cooling of the high-temperature zone of the base metal next to the weld quench-hardens that zone. Just as in ordinary heat treating, the maximum hardness in the weld heat-affected zone depends primarily on the carbon content of the casting. The maximum hardness may be increased somewhat by other elements, but their primary effect is to promote the retention of austenite by making its transformation more sluggish.

In the past, it was thought that hardness was directly related to underbead cracking, because underbead cracking was always found in zones of high hardness. It has recently been shown that this is not the whole story, and that factors other than hardness are necessary to produce underbead cracking. When free from cracks, the principal drawback of a hardened heat-affected zone is that it makes machining difficult.

Weld metal, too, particularly the earlier passes in multipass welds, is rapidly cooled by the quenching action of the unaffected base metal. It also is quench-hardened to a certain degree. However, its carbon content is generally quite low, and the amount of hardening is also low.

Fortunately, most castings with either repair or construction welds are at least stress relieved after welding. This eliminates detrimental hardness in the heat-affected zone.

Thermal Stresses

The rapid heating and cooling of the weld produce thermal stresses which may be quite large. During heating, there is a rapid expansion of the base metal around the weld. If the unaffected metal surrounding the weld zone is strong enough, or if the casting is rigidly clamped, the expanding metal in the weld zone will be upset. Upon cooling, the upset section will not return to its original dimensions, and internal stresses will be set up. Shrinkage of the solidified weld metal will also cause internal stresses.

If internal stresses in welded castings are high enough, they may cause hot cracks, or permanent distortion, and may propagate cold cracks. Unless they do produce one or more of these defects, internal weld stresses are not serious. They are essentially eliminated by any of the heat treatments ordinarily given castings after welding.

Hot Cracking

Hot cracking occurs while the heat-affected base metal or the solidified weld metal is still at such high temperature that it is unable to withstand even relatively low internal stresses. If stress is developed while the metal is in this weak condition, it tears instead of deforming, as it would at a slightly lower temperature.

In the casting being considered, hot cracks are more apt to occur in the weld metal than in the base metal. One reason for this is that the weld metal is hotter than the base metal and cools last. Also, because of directional freezing, weld metal has columnar grains. This structure is generally weaker than the equiaxed grains of castings.

Cold Cracking

The term cold cracking, i.e., cracking occurring at temperatures well below the critical temperature, has until very recently been applied exclusively to underbead cracking of the base metal in the heat-affected zone. Underbead cracking is caused by a combination of the structure formed by the high cooling rate in the high-temperature portion of the heat-affected zone, hydrogen from the arc atmosphere, and internal stresses.

Hydrogen is present in most arc atmospheres, though the amount varies greatly with different electrode coatings. During welding, hydrogen is dissolved by the austenite in the hot base metal adjacent to the weld. If the base metal cools rapidly enough to retain some austenite, there will be dissolved hydrogen concentrated in the austenite. When the austenite, which is unstable at ordinary temperatures, finally transforms, it releases the hydrogen. This forms in microscopic or submicroscopic voids in the base metal under very high aerostatic pressures. These pressures frequently start cracks, which are then propagated by the thermal stresses in the weld zone.

At least one investigation[3] has shown that steel castings are less prone to underbead cracking than wrought steels of similar composition. This investigation was limited to carbon-manganese steels, so it is not known whether this is a characteristic of other types of cast and wrought steels.

Recent work by Flanigan[4] and Bland[5] indicates that weld metal also may be prone to cold cracking. They have shown that even the ductilities of low-carbon weld

metals may be lowered by quenching. Microfissures have been found in weld metals so treated. Ductilities are not affected when preheats over about 300° F. are used. Low ductilities may be improved by postheating to temperatures around 600° F. It is thought that hydrogen may be the cause of the lowering of ductility in these weld metals, but this has not definitely been established.

When preheated or postheated, it is unlikely that the ductilities of welds in steel castings would be seriously affected by the cooling rates.

Porosity

Another serious defect sometimes encountered in welding is weld-metal porosity. This is caused by entrapped gases. Gases may come from the arc atmosphere, either by the breakdown of gas-forming components, particularly carbohydrates, or by decomposition of moisture picked up by the electrodes during storage. Gases may also be formed by reaction of elements in the base metal at welding temperatures. Sulphur is one of the leading porosity-forming elements. Weld-metal porosity may also be caused by welding over porous base metal, or by welding through sand pockets in the base metal.

Porosity can be minimized by slowing down the freezing of the molten weld metal. This allows the gases coming out of solution to escape to the surface of the weld metal. Where severe porosity is found, the weld should be chipped out, and the groove rewelded.

COMBATTING THE EFFECTS OF WELDING

The preceding sections have shown that, while there are a number of undesirable effects of welding, only four are found in repair welds of castings. These are, in the order of probable importance, cold cracking, hot cracking, permanent deformation and weld-metal porosity. Undercut and notches caused by improper fusion may also be found. They are the result of poor workmanship, not effects of welding *per se* so are not included in the preceding list. For the castings considered in this report it should be possible to minimize all four of these effects. The most effective step in the procedure for doing this is to slow down the heating and cooling rates of the weld metal and weld heat-affected zone. This is done by selection of suitable preheating and interpass temperatures, and postwelding heat treatments.

Preheat

Preheat reduces the temperature differential between the weld and the unaffected base metal. Chances of upsetting the heat-affected base metal by thermal expansion are thus decreased, but the principal benefits of preheating are those resulting from slower cooling of the weld zone, particularly at low temperatures in the range of martensite formation. Slow cooling promotes completion of austenitic transformation at higher temperatures in this range. This in turn eliminates the principal cause of underbead cracking. Slow cooling rates also lessen the chances of hot cracking, and lower the internal stresses set up during cooling.

Two types of preheat are used—general, in which the entire casting is heated, usually in a furnace; and local, where only a section around the weld is heated, usually by a gas torch or electric-resistance heaters. The former is always preferable, as it minimizes localized stresses. In foundries, furnaces for general preheating are at hand.

The preheat temperature depends on the properties of the casting and weld metal, and on the size and shape of the casting. There are certain general rules to follow in selecting the correct preheat temperature. In the first place, it should be as low as practically possible. This is because, with increasing temperature, it is more difficult to lay a weld bead without undercut, and protection for the welding operator becomes a problem. While the use of the minimum preheating temperature is desirable for the above reasons, a temperature of 50 to 100° F. above the minimum will seldom do any harm and, therefore, close calculation of the preheat temperature does not seem necessary. However, a good rule to apply when in doubt as to preheating would be always to preheat, or preheat at a little higher temperature.

The chemical composition of the casting is one major factor in selecting preheat. Steels low in carbon and alloy contents do not tend to quench harden excessively nor to form cold cracks. They require either no preheat, or much less preheat than needed for a high-carbon, high-alloy casting. This reasoning also applies to the deposited weld metal, particularly in multipass welds. In general, plain-carbon and low-alloy castings with carbon contents below 0.30% would not require preheat. For castings with carbon contents between 0.30 and 0.50%, preheats of 200 to 400° F. should be used. The higher side of this range would be used with the higher carbon and alloy contents, and increasing thickness and complexity of the casting. In some cases, where both the carbon and alloy contents are high, preheats over 400° F. may be necessary.

Thickness and shape of the casting also must be considered. Thicker castings have greater heat-absorbing capacities, and, therefore, in effect, greater quenching powers. As a rule, the thicker the casting (provided it needs preheat at all), the higher the preheat should be. Simple shapes with fairly uniform cross sections will cool uniformly, and require a minimum of preheat. Complex castings consisting of alternating thin and thick sections will cool more rapidly in the thin sections, which may lead to severe internal stresses. In such a case, a higher preheat should be used than for a more uniform shape. Also, they should be protected from drafts during welding, and should be cooled more slowly than less complex castings of the same composition.

Another factor influencing the selection of a preheating temperature is the size of the defect in relation to the thickness of the casting. A small weld cools more rapidly than a large one.

Thus, tack welding on a sensitive steel can be a dangerous procedure and casting failure has resulted from cracks started from a tack weld made without preheat.

In order to obtain the correct preheating temperature, furnaces with accurate controls can be used. When these are not available, Tempilstiks, which leave a mark that melts when the part reaches the required temperature, can be obtained for a wide range of temperatures within the normal preheating temperature range. Surface pyrometers are also available and very useful.

Interpass Temperature

The interpass temperature, i.e., the temperature between passes in multipass welds, should be considered along with preheat. In order to maintain the desirable conditions developed by preheat, the interpass temperature should never be below the preheat temperature. The interpass temperature can safely exceed the preheat temperature by 100 to 200° F., depending on the particular casting, and frequently does. The interpass temperature should not be allowed to go so high that the side walls of the weld groove will be severely undercut.

For rangy castings, the welding heat may not be enough to maintain the preheat temperature. In this case, additional heat is supplied by reheating the entire casting or locally heating the weld area.

THE WELDING OPERATIONS

After the preheating and interpass heating stages, the next stage in the welding procedure, where some correction of the effects of welding heat may be done, is the welding operation itself.

Choice of Electrode

Choice of electrode is one of the important steps in the procedure for welding a casting or several castings together. The arc atmospheres produced by different types and sizes of electrodes can affect the quality of a weld and the ease of welding.

Arc Atmosphere. It has already been mentioned that different arc atmospheres contain varying amounts of hydrogen, and that the amount of hydrogen depends on the composition of the coating. This varies for the different types of electrodes [which are discussed in detail in the complete S.F.S.A. manual from which this material is excerpted]. It is sufficient here to say that, by selecting types which will have arc atmospheres low in hydrogen, the chances for underbead cracking in the weld heat-affected zone will be minimized.

Heat Input. Some classes of electrodes require higher welding currents for a given diameter than others, and, consequently, have higher burn-off rates, i.e., deposit more metal in a given time. Also, larger diameter electrodes of a given class require more current than smaller ones. Increasing the current increases the welding heat input. This acts, to a lesser degree, like preheating, flattening out the temperature differential in the weld area, and lowering the cooling rate. Therefore, other things being equal (which they frequently are not), the "hotter," larger diameter electrodes should be selected for repair welding.

Welding Current

The welding current used with a certain size of electrode may also be varied somewhat, when welding in a given position, e.g., downhand. It usually has to be varied for welding in other positions, e.g., vertical.

Manufacturers usually print the recommended current ranges for their electrodes on the containers. These ranges will vary somewhat even for electrodes of the same class. Usually the ranges are rather wide. The higher currents are for downhand welding under favorable conditions. Those on the lower side are for situations where careful control of the weld metal is needed, such as in vertical or overhead welding, or where the preheat is high.

Experienced welders can select the proper current. Some will tend, however, to use higher currents than they should in order to get out more work. Poor welds may result, if this is allowed.

In Table 2, typical current ranges are given for three commonly used sizes of electrodes for plain-carbon and low-alloy steel castings.

As already mentioned, higher welding currents will give higher welding heat inputs, which are frequently advantageous. However, for making a good weld with a given size and type of electrode, in a given position, the variation in welding current cannot be too great.

Deposition Technique

There are many ways of depositing a weld bead in a groove. Usually, there are one or two ways that are best for certain welding jobs. Their selection depends on the size of the groove, the thickness of the casting section and the properties of the casting and weld metal. The position that the weld is to be made in must also be considered, as the deposition technique for position welding is different than that for downhand welding. However, position welding for castings repair is so rare that it can be neglected in this discussion.

There are two basic factors that have to be considered in selecting the proper deposition technique. These are the speed of welding and the volume of the weld. These two factors may be varied to help control welding heat effects. For a given size of weld bead, the higher

Table 2—Typical Current and Arc-Voltage Ranges for Mild and Low-Alloy Steel Electrodes*

A.W.S.-A.S.T.M. electrode class	Electrode diameter, 1/8 in. Amp.	1/8 in. Arc volts	5/32 in. Amp.	5/32 in. Arc volts	1/4 in. Amp.	1/4 in. Arc volts
EXX10 and EXX11†	80–120	24–26	140–220	26–30	200–300	28–32
E6012	80–130	18–22	140–250	20–24	200–400	20–24
EXX13	70–120	18–22	140–240	20–24	200–350	22–26
EXX15 and EXX16	100–150	20–22	160–240	22–24	300–375	24–27
EXX20 and EXX30	100–140	24–28	175–250	30–36	250–400	30–36

* From the *Welding Handbook*, AWS, Table 1, p. 846.
† The symbols "X" are used to represent a group of related electrode classes. For example, EXX10 represents Classes E6010, E7010, E8010, etc., while E60XX would represent Classes E6010, E6011, E6012, etc.

the welding speed, the more rapid the cooling rate. This increases the underbead hardness and tendency to underbead cracking. On the other hand, it reduces the tendency to distortion by minimizing the volume of heat-affected base metal. The effects of slower speeds are the converse. When preheat is used, welding speed—provided a sound, well-contoured bead is laid—is not important.

The effects of volume of the weld are quite similar to those of speed, a small weld producing effects quite similar to those with high speed, because, again, the cooling rate of the weld zone is relatively fast. Conversely, a large volume of weld metal deposited in a single pass results in considerably more heat in the weld zone. This gives a slower rate of cooling in the weld zone, but higher shrinkage stresses. Of course, unless the shrinkage stresses are sufficiently high to cause cracking in the weld metal or base metal, they are of no particular importance in repair welds, where the castings will usually be at least stress relieved after welding.

There are two main types of weld beads, the string bead and the weave bead. The string bead is laid in a continuous pass in one direction. This is shown in Fig. 1. The weave bead also progresses in one direction, but also has a side-to-side motion. There are many patterns of weave bead, including simple ones such as illustrated in Fig. 2—figure eights, ellipses, etc. A modification of the weaving technique which can be used with many of the weave patterns is whipping. This is used to control the molten weld pool by removing the arc heat, while still maintaining the arc. A schematic whipping pattern is shown in Fig. 3.

String and weave beads are used in single layers, when the groove can be filled in a single pass. Where the groove is too deep or too wide for it to be filled in one pass, multiple layers are used. These may be laid with either string or weave beads, or a combination of the two.

Still another way of controlling the welding heat effects by deposition technique is the welding sequence. This can be varied even in single-layer welds. The most common sequence for single-layer welds is simple string or weave beads laid in one direction. These are started at one end of the weld and continued to the other. Where the weld is long, several electrodes may be used. In this case, the beads are laid one after the other in the same direction. In long welds where it may be desirable to minimize longitudinal and transverse weld shrinkage effects, the back-step method can be used. In this procedure, short lengths, say 2 to 4 in., are deposited in the sequence shown in Fig. 4.

In multiple-layer welding, there is still a greater variety of sequences that may be used. Again, string or weave beads laid in one direction are most commonly used. The step-back sequence can also be used, either as string beads or weave beads. Two other sequences designed primarily to minimize shrinkage in fairly large groove welds are the block sequence and the cascade sequence. In the block sequence, the weld is

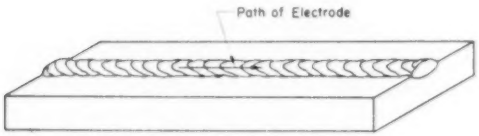

Fig. 1 String bead

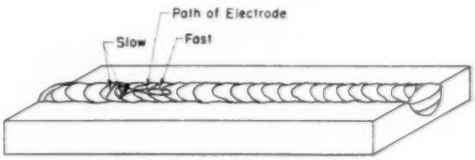

Fig. 3 Weave bead with whipping

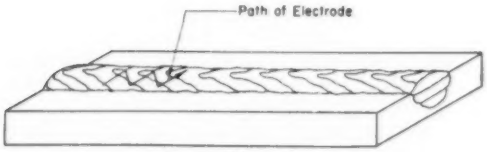

Fig. 2 Weave bead

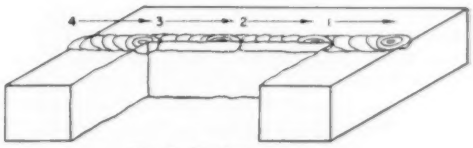

Fig. 4 Backstep sequence

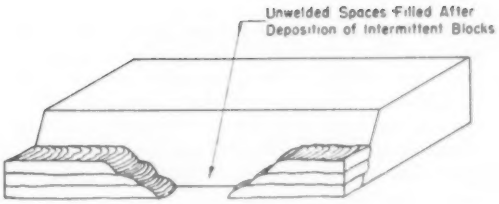

Fig. 5 Block sequence

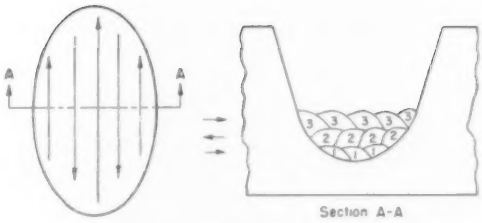

Fig. 7 Horizontal-layer deposition

built up by intermittent blocks which are subsequently joined by other blocks after the first group is completed. This procedure is shown in Fig. 5. The chief benefit of the block sequence is to minimize longitudinal weld stresses. It does not have much effect on transverse shrinkage, except as the stresses in the lower passes are relieved by the welding heat from succeeding passes. The cascade sequence reduces both transverse and longitudinal shrinkage stresses as the weld progresses, particularly when used with a weaving bead. The sequence is shown in Fig. 6. By using it, the heat from the first half of any bead will tend to temper or stress relieve the last half of the bead immediately before it. The net result is that all segments of the first-pass bead are stress relieved by the next succeeding increment so that no major locked-up stresses can remain. Both of these methods require more welding time than ordinary multilayer welds. They should not be used, except where the greater reduction of stress warrants it. Preheating would largely eliminate need for such special techniques.

For the multilayer welding of large grooves, any one of the deposition techniques discussed can be used. Sometimes, as a matter of convenience, it is simplest to run one bead in one direction and the next bead in the opposite direction. In general, the simplest procedure is to build up the weld in horizontal layers, such as illustrated in Fig. 7. It has been claimed[6] that the least stress is produced when the weld can be built up in spiral layers around the side, as shown in Fig. 8.

Nearly all repair welds in castings can be made with string or weave beads laid from start to finish in single or multiple layers.

In the section on preparation for welding, the use of backings was discussed. In general, the presence of a backing does not markedly change the required deposition technique. However, particular care must be taken in laying the root passes. Where a backing is to become a part of the assembly, it is very important to see that full penetration into the backing is obtained. Where a temporary backing, either ceramic or ceramic-washed metal, is used, particular care should be taken to insure good fusion between the root pass and the side walls of the groove. If this is not done and there is lack of fusion between the root pass and the side walls, the unfused sections will act as stress raisers. Stress raisers naturally increase the possibility of cracking.

Another step in deposition technique which can be extremely important is arc length. Ordinarily, a good welder automatically holds a proper, or "normal" arc length. For the low-hydrogen type electrodes—AWS-ASTM Classes EXX15 and EXX16—the arc required for depositing high-quality weld metal is shorter than for other classes of electrodes. This is an important difference which may be overlooked even by good welders, whose experience has been with the other classes of electrodes. They should be frequently reminded of this difference, until they have become thoroughly familiar with the low-hydrogen electrodes.

Good deposition technique, though important, is generally not too difficult to choose. Competent operators may not all use the same technique—in fact, they almost certainly will not—but with relatively little guidance, they will choose one that will do the job satisfactorily.

Peening

Distortion is sometimes minimized by peening the weld. Heavy peening after each pass will reduce distortion by "spreading out" the weld metal, thus counterbalancing its natural shrinkage. For castings thick enough to resist distortion, deep peening gives a mechanical stress relief. Peening must be carefully controlled, because overpeening causes weld-metal cracking, and is, therefore, worse than none.

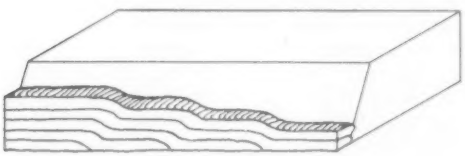

Fig. 6 Cascade sequence

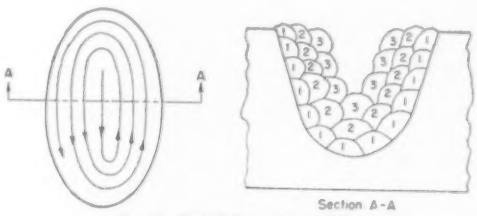

Fig. 8 Spiral-layer deposition

The permissible amount of peening is somewhat dependent on the mass of the casting, heavier peening forces being required for heavier castings.

For castings which are to be at least stress relieved after welding, peening would generally not be used. Where severe distortion during welding might occur, for example, in filling a relatively large groove in a thin rangy casting, peening may be helpful in minimizing distortion.

Postwelding Heat Treatment

The great majority of castings can be cooled to room temperature in still air after welding, but those of higher composition, which are more sensitive to cracking, should have retarded cooling from the welding temperature. This is primarily to give greater insurance against cold cracking. Such retarded cooling may be accomplished by heating with a flame or burying the casting in some insulating material. However, inasmuch as crack-sensitive steels require preheating as well, one of the best practices is to put the castings back in the preheating furnace as soon as welded.

All welded castings except some of the low-carbon unalloyed steels should be given a postwelding heat treatment. The minimum treatment should be a stress relief, which consists of heating to 1100 to 1250° F. Such a treatment will remove practically all residual stresses and prevent any subsequent cold cracking, but most important, it will reduce the hardness of the heat-affected zone to the point where machining or chipping will present no problem.

Many castings will be given their regular final heat treatment, such as normalizing or quenching and tempering. Either of these treatments will eliminate the heat-affected zone and, of course, make the stress-relieving treatment unnecessary. Though normalizing or quenching and tempering generally improves the base metal, they may reduce the weld metal properties, unless suitable electrodes are chosen.

(*Editor's Note:* As indicated, the above comprises merely an excerpt from the 40-page Steel Founders' Society manual—being concerned primarily with welding methods. Other sections of the comprehensive manual are devoted to detailed textual consideration and tabular classification of electrodes and trade names and manufacturers for all classes of electrodes; special sections on compositions and recommended procedures for carbon steel and low-alloy steel castings, bibliography, etc.

(Copies of the complete, bound manual, *Recommended Practice for the Welding of Steel Castings*, may be obtained by writing to F. Kermit Donaldson, Executive Vice-President, Steel Founders' Society of America, 920 Midland Bldg., Cleveland 15, Ohio. The price, fixed at cost, is 35 cents per copy.)

References

1. Welding Handbook, American Welding Society, New York, New York, 1950.
2. Henry O. H., Claussen, G. E., and Linnert, G. E., "Welding Metallurgy," American Welding Society, New York, 1949.
3. Williams, R. D., Roach, D. B., Martin, D. C., and Voldrich, C. B., "The Weldability of Carbon-Manganese Steels," Welding Journal, **28**, (7), 311-s to 325-s, 1949.
4. Flanigan, Alan E., "An Investigation of the Influence of Hydrogen on the Ductility of Arc Welds in Mild Steels" Welding Journal, **26**, (4), 193-s to 214-s, April 1947.
5. Bland, Jay, "Effect of 'Quench Time' on Weld Metal," Welding Journal, **28**, (5), 216-s to 226-s, 1949.
6. Pomfret, R. A., "Removal and Repair of Steel Casting Defects," *Trans. of Am. Foundryman's Assn.*, **33**, 191–195 (1945).

Resistance Variations During Spot Welding

Discussion by H. Udin

Mr. Roberts is to be congratulated for an excellent piece of work. Two of his conclusions are of fundamental importance. First, that the weld nugget, like the welding arc, is nearly a constant-voltage load. Second, that weld power over the greatest part of the welding cycle is independent of electrode force. The most difficult job the welding engineer has is to separate the effects of a great number of interdependent variables. Pinpointing two of the more important variables will ease this problem considerably. Incidentally, while Roberts makes the first point for metals of high conductivity such as aluminum, a study of his Table 2 shows that it is not too bad a first approximation for stainless steel, a metal at the other end of the conductivity scale. One must consider that the fraction of the voltage drop caused by the bulk resistance of the plate is largely wasted in so far as making the weld is concerned. Since this voltage must increase somewhat more than proportionally to the current, it is probable that even for stainless steel the "contact" voltage is nearly independent of current.

A study of the work on cold resistance leads to some interesting results. According to constriction resist-

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Paper by W. L. Roberts published in November 1951 issue The Welding Journal, pp. 1004–1019.

* In the light of Roberts' findings on resistance variations with current, one wonders how the industry has managed to stagger along for so many years with our old friend $H = I^2RtK$. I think the answer lies in the fact that while resistance is inversely proportional to current, heat loss bears some increasing relationship with time. Thus two gross errors, the assumption that R is constant and the assumption that K is constant, tend to cancel.

ance theory, the cold contact resistance per unit area across an electrode-to-work interface should be approximately

$$R = \frac{0.9\rho}{4na} \qquad (1)\dagger$$

where ρ is the bulk resistivity of the work, assumed much greater than that of the electrode. n is the number of metallic bridges and a is the average mean radius of the bridges. As two surfaces are brought together they make physical contact at only a few scattered high spots. With increasing pressure these spots deform plastically and the true bearing area increases. From this the fractional bearing area is simply

$$f = \frac{P}{Y} + A' \qquad (2)$$

where P is the applied unit pressure and Y is the compressive yield strength of the softer member. P/Y represents plastically strained material in bearing contact, while A' represents elastically strained contact area. At low unit pressures A' is about equal to P/Y, but at high pressures it probably becomes negligibly small. Within the bearing area the oxide films rupture and a certain amount of metallic contact occurs. If a fixed fraction c of the true bearing area is in metallic contact, we can state that

$$f' = \frac{cP}{Y} = \pi a^2 n \qquad (3)$$

where f' is the fractional area in metallic contact.

Substitution of Equation 3 into Equation 1 can be made on the basis of either of two simplifying assumptions:

(*a*) n remains constant with increasing pressure.

(*b*) a remains constant with increasing pressure.

Assumption (*a*) leads to

$$R = \frac{0.9\rho\sqrt{\pi Y}}{4\sqrt{ncP}} \text{ ohm cm}^2 \qquad (4)$$

while (*b*) leads to

$$R = \frac{0.9\ \pi\rho a Y}{4\ cP} \text{ ohm cm}^2 \qquad (5)$$

I have replotted Roberts' data for cold contact resistance of mild and stainless steels versus copper alloy and find, rather surprisingly considering the drastic assumptions, that between forces of 200 and 700 lb., Equation 4 is obeyed rather well. Nearly within experimental error most of the curves follow

$$1/R = K\sqrt{F} \qquad (4a)$$

K is of course different for each sample. From 700 lb. to the maximum force used there is reasonably good agreement with Equation 5 to the extent that the equation

$$1/R - G_{700} = K'(F - 700) \qquad (5a)$$

holds. Here G_{700} is the conductance at 700 lb. force.

The agreement can be explained on the basis of the following sequence of events. At low pressures increasing force results in fragmentation of the oxide layer in a complex manner, the oxide failure being chiefly in bending. By the time the pressure reaches about 0.2 Y the oxide rafts are small enough that they can move as units to accommodate their orientation to the localized plastic flow. Then, as the pressure continues to increase the fissures get larger, but no additional fissuring occurs. At about 0.7–0.8 Y the surface strain approaches uniform biaxial tension (as in the cold-welding process). The rafts of oxide are now trapped by the nearly completely mated surfaces. Fissuring once again begins, with oxide failure occurring in tension. This stage results in an increase in the number of metallic bridges.

Experiments of Holm and others indicate that the number of spots in electrical contact at low and medium pressures is of the order of twenty-five per square centimeter. Substitution of this into Equation 4 leads to the rather interesting result that some 10–20% of the *bearing* area of stainless steel against electrode alloy is in true metallic contact. Note that this refers to the bearing area, not to the apparent contact area (identical to the electrode area). In the electrode/mild steel interface only 0.01–0.05% of the bearing area comes into electrical contact. This value for stainless seems rather high, and it is possible that with freshly cleaned electrodes much of the stainless-to-electrode bearing area conducts by tunnel effect. If so, the rectifier action of the semiconductive copper oxide film on the electrodes may explain the change of resistance with current reversal.

Most of this analysis is admittedly highly speculative and oversimplified. However it is my belief that an analytical approach to resistance welding is possible and desirable. When this approach is finally made it will lean heavily on data such as those collected by Mr. Roberts.

† Holm, Ragnar, *Electric Contacts*, Gebers, Stockholm, p. 93 (1946).

Current Welding Literature

(*Continued from page 305*)

Pipe Lines. Using Oxyacetylene Processes for Fabricating Piping, E. P. Auler. Heating, Piping & Air Conditioning, vol. 23, no. 7 (July 1951), pp. 102–105.

Pipe Lines. Welding Pipe and Tubes of Nickel and High-Nickel Alloy. Heating & Vent., vol. 48, no. 8 (Aug. 1951), pp. 77–80.

Pressure Vessels, Welding. Aspects of Pressure Vessel Conversion, J. K. Johannesen. Welding & Metal Fabrication, vol. 19, no. 12 (Dec. 1951), pp. 474–475.

Rail Welding and Reconditioning, F. M. Burt. Welding Engr., vol. 36, no. 12 (Dec. 1951), pp. 32–34.

Saws, Manufacture. Welding Band-Saw Blades, H. J. Chamberland. Am. Foundryman, vol. 20, no. 6 (Dec. 1951), pp. 53–54.

(*Continued on page 329*)

Pipe Weld Normalizing and Stress Relieving

Application of 60-cycle induction heating for normalizing and stress relieving welded pipe joints

by C. A. Anderson, D. H. Corey and H. J. Denman

Abstract

The heat treatment of pipe welds in power plant steam piping has long been done by 60-cycle induction heating. An article published several years ago in THE WELDING JOURNAL* describes this method of heating and normalizing pipe welds at 1725° F. and the resultant metallurgical effects. This present article deals with an improvement in the application of the 60-cycle induction heating method: the metallurgical effects should not be changed by the electrical circuit changes described in this article. Design computations and some of the lessons learned in the field are also included.

THE method of heat treating pipe by 60-cycle induction heating described by Corey and Rohrig* utilized $^1/_2$-in. copper tubing for the inductor coil. This tubing was covered with asbestos sleeving as turn-to-turn insulation. Several layers of asbestos paper were wrapped around the weld zone forming a $^1/_8$ to $^1/_4$-in. layer of simultaneous thermal insulation and electrical insulation between the pipe and the inductor coil. Several lengths of $^1/_2$-in. copper tubing were connected together with couplings until the desired number of turns was obtained. This inductor coil then formed an electrical path and a cooling water path consisting of all turns in series. The inductor coil was fed from a transformer having numerous secondary taps from 18 to 192 v. and having a primary suitable for operation at 230 or 460 v. The coarse adjustment for temperature control of the weld zone was obtained by switching secondary taps, and the final temperature adjustment was obtained by on-off switching of power.

The objections to the inductor coil in its old form were as follows: (*a*) The uninsulated couplings occasionally dug into adjacent turns and caused turn-to-turn short circuits. (*b*) The stiff tubing and the bulky couplings made it difficult to produce a neat symmetrical inductor coil. If this lack of symmetry resulted from bunching of the coil turns on one side of the pipe and spreading of them on the other, unequal temperatures would develop on opposite sides of the weld zone. (*c*) A water leak at one of the pipe fittings was often troublesome to correct since it might be buried under another layer of turns. (*d*) The tubing was difficult to assemble on the pipe especially if work-hardened by previous handling. (*e*) After the tubing had been used about four times it had to be annealed. This entailed removal and replacement of the asbestos sleeving and the coupling at one end because annealing was done at red heat. The objection to the use of the transformer, in addition to that of cost, bulk and weight, was that the power available for heating the weld zone was limited by the kva. capacity of the transformer.

In the new method, power from a 230-v. a.-c. source is applied directly to the inductor coil on the pipe without the interposition of a transformer. The method hinges upon the use of a unit coil like that shown in Fig. 1. As many of these coils as necessary are assembled on the pipe over a layer of pipe covering. They are connected in series electrically and centered over the pipe weld. For cooling, the water path is divided into whatever series-parallel combination may be required. This is shown later. The new inductor coils essentially eliminate the five objections listed for the old inductor coil, in addition to eliminating the need for a transformer when 230-v. service is available. For 460-v. service twice as many turns are needed as for 230 v. The installation of so many turns may make the use of a transformer preferable when one is available.

As previously mentioned, with the step-down transformer, temperature control was obtained by tap changes on the transformer for coarse adjustment, and by on-off cycles of power for the final adjustment. Without the step-down transformer, coarse adjustment for temperature control is obtained by varying the number of unit coils used to form the inductor coil, and final adjustment is obtained by on-off switching of power.

The unit coils are made of 25-ft. lengths of rectangular copper tubing. The copper cross section of the coil shown in Fig. 1 is 0.37 by 0.21 in. by 50-mil wall. An even wider, more ribbon-like cross section might be more desirable. Our experience has shown that a narrower one is not desirable; it tend's to wind diagonally. Cooling water terminals are formed by brazing a short piece of $^3/_8$-in. round copper tubing to each end

C. A. Anderson is connected with the Research Dept. of the Detroit Edison Co.; **D. H. Corey** and **H. J. Denman** are connected with the Construction Engineering Dept. of the Detroit Edison Co.

* Corey, D. H., and Rohrig, I. A., "Normalizing of Welds in Carbon-Molybdenum Steel Pipe by 60-Cycle Induction Heating," THE WELDING JOURNAL, **24** (1), 1–6 (1945).

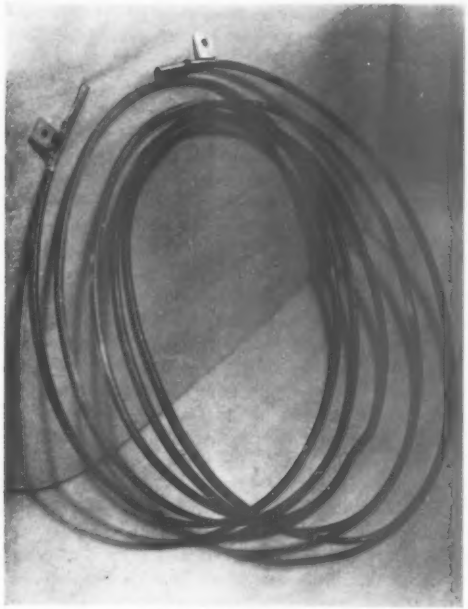

Fig. 1 A unit coil

of the rectangular tubing. The electrical terminals are $^1/_8$-in. thick, 1-in. wide copper lugs which are brazed on in a standardized location to minimize the chance of coils being connected in reverse. The coils are insulated with a heavy fiberglass sleeving (12-mil wall) impregnated with silicone varnish and baked at 500° F.

This high temperature type of insulation was selected for two reasons. First, the insulation may be exposed to direct radiation from the 1725° F. pipe through an accidental opening in the pipe covering. Such exposure under the conditions normally existing in such weld-normalizing work does not injure this insulation. Second, the insulation permits annealing of work-hardened coils without requiring replacement of insulation. It is anticipated that the bending of the coils incidental to installation and removal may eventually work-harden the copper until the coils are too stiff for easy handling. The coils can then be annealed to a suitable degree by holding them at 600° F. for 8 hr. Annealing to "dead soft" as was done with the $^1/_2$-in. round tubing is undesirable for the smaller rectangular tubing because it is then too easily kinked. If necessary, the annealing can be followed by another coat of silicone varnish. In 2 yr. of use there has been no evidence of serious work-hardening from normal handling. Rough handling has twisted the tubing so that annealing is useful for easing the task of straightening.

Figure 2 illustrates the method of assembly of the coils on the pipe. A length of high-temperature pipe covering is placed over the weld zone. The unit coils are "snaked" onto the pipe one at a time, then wound into neat coils over the pipe covering and tied with ordinary cotton string. Figure 2 shows a unit coil partly snaked on at a point where the pipe is bare. Another coil is hanging loosely over the high-temperature pipe covering, and three coils have been wound and tied. Figure 1 shows a jog in the center of the 25-ft. length of each coil. The coils are wound in position by starting at this jog and winding in both directions to form two opposing spirals.

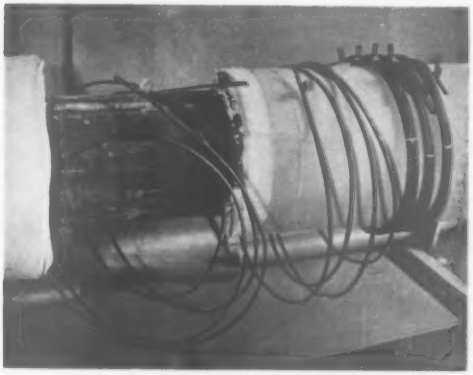

Fig. 2 Unit coils being assembled on pipe

Figure 3 shows 10 unit coils assembled in place. Half of the required rubber hoses for the cooling water paths have been connected from the coils to the inlet and outlet manifolds. Short hoses are used to connect coils in series. The 10 coils are arranged for cooling in five parallel water paths, each path consisting of two coils in series. Electrically, all coils are connected in series. Asbestos rope is used as a spacer between coils and for

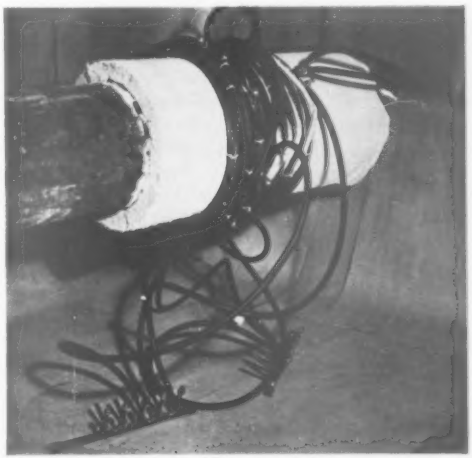

Fig. 3 Ten unit coils with electrical connections completed. Half of the cooling water hoses are in place, and nearly half of the asbestos rope used for anchoring and spacing the coils

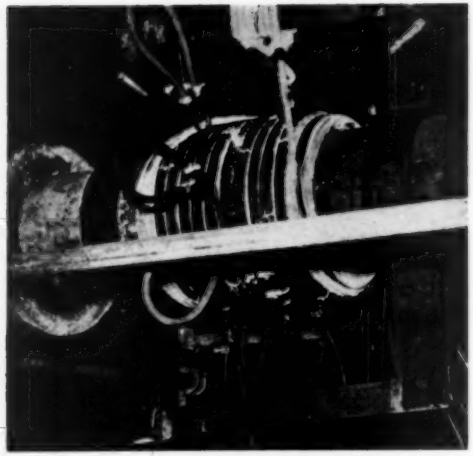

Fig. 4 Delray Power Plant. A welded joint being normalized

securing the coils in place. The illustration shows about one-third of the asbestos rope in place.

Figure 4 shows a weld being normalized in the Delray Power Plant of The Detroit Edison Co. The large rectangular clamping bracket was present in this instance during both the welding and normalizing operations to maintain the "cold spring" in the pipe. The figure shows that 10 unit coils were used. An 18-in. length of pipe covering was used under the coils.

COMPUTATION OF COIL AND KVA. REQUIREMENTS FOR A TYPICAL PIPE WELD

To hold a portion of pipe at a given temperature the same amount of energy must be delivered into this portion of pipe as is being dissipated from it. So the first requirement is to determine the amount of this heat dissipation. The greatest single heat loss, heat dissipation from the outer surface of the pipe, can be reduced to a negligible amount by the use of pipe covering. A 36-in. length of pipe covering centered over the weld zone will generally be ample. Since the inductor coils will be wound on top of the pipe covering, the pipe covering thickness should be a compromise between good inductor coil coupling efficiency and good thermal insulation. A thickness of $^1/_2$ in. of good insulation would be ideal, but so thin a covering would be too flimsy. The available $1^1/_2$-in. pipe covering is not too serious a departure from this optimum when used on 8-in. or larger pipe.

Heat losses within the pipe usually cannot be reduced. One of these is the heat loss by thermal conduction in the wall of the pipe. It can be calculated readily if a temperature gradient is assumed. A greater loss at high temperatures, such as 1725° F., is the infrared radiation shining through the hollow interior of the pipe. The calculation of this loss requires consideration of the restricted angle through which this radiation can take place.

There is another form of heat dissipation that may be present and which must be stopped or reduced to negligible proportions. Leaky valves may permit some steam or water to move through the pipe from an operating portion of the piping system. This may be serious, for the steam may constitute a means of heat transfer by which the weld zone loses its heat to the connected piping system just as a steam boiler gives up its heat to the steam radiators of the heating system in a building. A small amount of steam leakage can usually be vented so that only a small increase in kw. input to the weld zone is required to offset the heat carried away by the steam. Usually convection losses carried by the air within the pipe can be ignored.

The sum of the two main losses, thermal conduction through the metal of the pipe and radiation through the interior of the pipe, determines the power which must be delivered into the weld zone to hold it at the desired temperature. If this value of power input is doubled it will provide ample leeway for bringing the weld zone up to temperature in a reasonable length of time and will allow for the factors which individually were dismissed as negligible.

A 10-in. pipe would have a heat dissipation from a weld zone at 1725° F. of about 11 kw. if pipe covering is used and no serious convection losses are present inside the pipe. An input of 20 kw. to the weld zone while it is at 1725° F. would be desirable in this case.

The current path in the pipe may be assumed to be as wide as the spread of the inductor coils. If the inductor coils were spread over a 12-in. length of pipe the current path in a 10-in. Schedule-100 pipe would have a resistance at 1725° F. of 172 microhm. (At 1725° F. mild steel has an electrical resistivity of approximately 120 microhm-cm.) To produce 20 kw. in this resistance the voltage induced in the pipe must be 1.86 v. The volts-per-turn in the inductor coil will have to be greater than the voltage induced in the pipe by approximately the ratio of their enclosed areas. This relation would be exact if the inductor coil were very long and the pipe wall very thin. In the present case it is still close enough for practical purposes. The mean diameter of the 10-in. pipe wall is 10 in. and that of the inductor coils assembled over $1^1/_2$-in. pipe covering is $14^1/_2$ in. The ratio of their enclosed areas is 1 to 2.1 so the volts-per-turn in the inductor coil should be 3.9 v. to induce 1.86 v. in the pipe. For 230-v. operation the inductor coil should therefore consist of 59 turns.

The current drawn by the inductor coil from the 230-v. bus when the weld zone is at 1725° F. is largely determined by the inductance of the coil in free space. As computed by one of the simpler formulas this 59-turn coil has an inductance in air of one millihenry, and a 60-cycle reactance of 0.377 ohm. At 230 v. this coil in free space should draw 610 amp. Actually, mounted on the pipe, it will draw somewhat less because of the presence of magnetic material such as the portions of

the pipe beyond the ends of the coil where the pipe temperature is below 1400° F.

In actual practice 10 of the unit coils shown in Fig. 1 are used. These result in about 64 turns for the 10-in. pipe. The computed inductance in air of this coil group is 1.16 millihenry and its 60-cycle reactance is 0.44 ohm. The actual supply voltage at the coil terminals is usually 220 v. or less and the maximum current is close to 450 amp. which means an impedance of 0.49 ohm. When the desired temperature cannot be attained with 10 unit coils the volts-per-turn are increased by using only nine unit coils, in which case the maximum current is closer to 550 amp. This constitutes the coarse adjustment mentioned earlier. With experience, it is rarely needed.

The resistance of 10 unit coils of the size described earlier is 0.048 ohm. The cooling water serves only to carry away the I^2R copper losses in the inductor coils. The maximum current allowable in the inductor coils is dependent on the pressure and temperature of the cooling water. A current rating for these unit coils for a water pressure of 25 psig. and 50° F. temperature rise is 600 amp. if each water path consists of two unit coils in series, and 1000 amp. if each water path consists of one unit coil.

Over-all thermal efficiency at 1725° F. is 50 to 70%. Admittedly 60 cycles is too low a frequency for maximum efficiency of energy transfer from inductor coil to pipe, but the convenience of making direct use of the available 60-cycle supply, and the elimination of the initial cost and losses of a frequency converter, make the use of a higher frequency for pipes of 4 in. diameter or larger of doubtful value. If the low power factor of the load is undesirable it is cheaper to use enough capacitors for power factor correction to unity than to buy the necessary high-frequency equipment.

The temperature gradient which exists along the pipe on either side of the weld zone is shown in Fig. 5. Here are illustrated the effects of using two extremes: *A*, spread coils and a long length of pipe covering as contrasted with *B*, bunched coils and a short length of pipe covering. Both of these cases represent butt joints in a straight section of pipe.

When the weld is close to a flange, valve, tee or bracket, bunching of the coils may be unavoidable. Then heat dissipation along the pipe is greater in one direction than in the other and it is necessary to counter this by shifting the coil an inch or two off center in the direction of the heavier metal. When the pipe is thus unsymmetrical any heavier metal inside the inductor coil heats more slowly below the Curie point and more rapidly above the Curie point than does the thinner metal. This produces a shift in hot spot location during the heat cycle.

Usually the pipe and adjacent flanges or valves have sufficient circumferential symmetry so that the heat pattern in the weld zone has circumferential uniformity. In this case, four thermocouples are used for temperature control and observation of heat pattern. One in the center of the weld zone, plus a spare, is used for

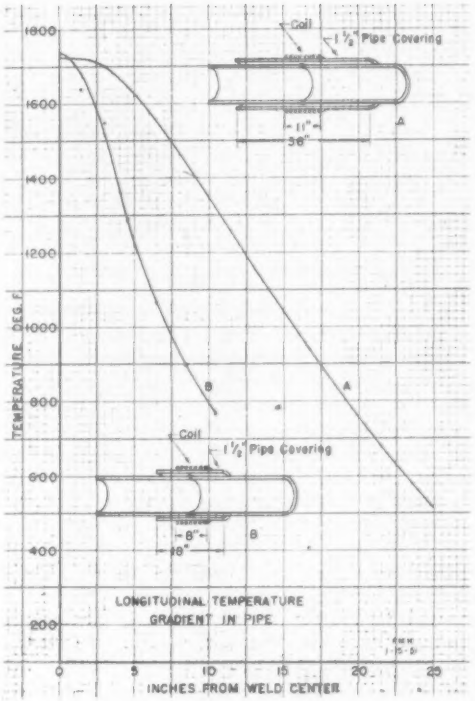

Figure 5

the automatic temperature controller and recorder described later. The other two are located 1½ in. each way from the weld zone center. They are connected to a manually operated potentiometer and serve to indicate whether or not the heat pattern is centered in the weld zone.

If the weld zone or the adjacent piping for 18 in. either way lacks circumferential symmetry it would be well to place thermocouples in each quadrant of the weld zone. These thermocouples will indicate whether or not the resultant nonuniformity of temperature is sufficient to require correction. Correction may be obtained by one or both of two methods. First, the heat dissipation pattern may be altered by cutting away portions of pipe covering on the hot side and putting additional pipe covering on the cool side. Second, the heat input pattern can be altered by bunching the inductor coils on the cool side and spreading them on the hot side.

No serious lack of circumferential temperature uniformity in the weld zone of a butt joint on the stem of a T has been observed. Such lack of temperature uniformity might be expected if only one arm of a T were heated. A 50° F. temperature differential was observed when only one arm of a Y connection was heated to an average weld zone temperature of 1700° F.

An interesting feature is the effect of change in pipe

size on the number of inductor turns needed to provide the necessary kw. input for holding the weld zone at 1725° F. It has been found that for the range in which these coils have been used, 8- to 14-in. pipe, it is necessary only to use a fixed number of unit coils for any pipe size of a given pipe schedule and the necessary change in number of coil turns takes care of itself. The larger pipe sizes operate at higher power factors so that while the kva. changes but little with pipe size the kw. input changes essentially as needed.

STRESS RELIEVING AT 1200° F.

Stress relieving at 1200° F. because of its lower temperature involves much lower heat losses from the weld zone than does a normalizing operation at 1725° F. Moreover, the fact that 1200° F. is well below the Curie point makes power input to the weld zone occur at a much higher power factor. In general, stress relieving could be done with a maximum kva. one-third as great as that required for normalizing. Maximum kva. in normalizing work occurs when the weld zone is at its maximum temperature of 1725° F. Maximum kva. for stress relieving at 1200° F. or lower occurs when the pipe is cold. To decrease the power input to the weld zone and correspondingly the kva. from the line, it is necessary to reduce the volts-per-turn at the inductor coil. This is accomplished by increasing the number of coil turns if the inductor coil is fed directly from a fixed voltage supply such as a 230-v. bus.

Of course, any amount of power greater than a required minimum may be fed to the weld zone. The temperature is then controlled by using a shorter "on" time for the higher power input. If it is necessary to keep kva. to a minimum the number of turns used for stress relieving should be about 50% more than that used for normalizing for direct operation from a fixed voltage supply.

When the number of turns needed is not known, the simplest procedure is to install what appears to be more unit coils than necessary, connect them all in series, and center them over the weld. If the temperature rise is too slow with 230 v. connected across all of the unit coils, the leads should be reconnected to exclude one or more unit coils from each side. With a cold pipe of mild steel the power input to the pipe varies as nearly the cube of the volts induced in the pipe, so a small change in number of coil turns makes a large change in rate of temperature rise. Line kva. will vary between the cube and the square of the volts-per-turn because other factors are present besides that of power input to the pipe.

The computation of power input for temperatures below the Curie point is more involved than the problem given earlier of heating a 10-in. Schedule-100 pipe to 1725° F., so no attempt has been made to give it here.

CONTROL EQUIPMENT

Figure 6 shows a view of the control unit. The con-

Fig. 6 240-v., a.-c. stress reliever and normalizer controls (front of unit)

ductors from the 230-v. bus to the control unit and from the control unit to the inductor coils each consist of 100-ft. lengths of No. 4/0 Awg extra flexible welding cables. A 600-amp. safety switch and a contactor comprise the feed through the control unit. Fusing at the 230-v. bus only. For the contactor a 3-phase, 120/208-v., 150-kva. network protector was used because it is a stock item, otherwise a 600-amp. single phase controller would be used. The network protector is motor operated, and is limited to 50 operations per hour to avoid overheating of the motor. The overcurrent relay on the protector is set for 600 amp.

Instrumentation consists of a recorder-controller, a manually operated potentiometer with a 6-point selector switch, an ammeter and an electric clock. A 220/110-v. auto transformer is tapped into the 230-v. circuit to supply 115 v. for lighting, recorder chart drive and the clock. Current transformers for the ammeter and overload relay are a standard part of the network protector. A double throw control switch permits the operation of the control unit to be either automatic or manual.

Safety features of the unit include locks on all doors except the instrument and controller compartment. With the unit in its operating position it is impossible for anyone to come in contact with live parts of the equipment. During operation the frame is grounded with a separate heavy ground lead.

The lower half of the instrument compartment cover forms a desk for convenience in taking readings. Below the instrument compartment is a space for tools, ink, pen, charts, record sheets, etc. The whole unit is mounted on roller bearing wheels for easy maneuverability.

Thermocouple wiring at the weld consists of a 6-ft. length of solid No. 19 Awg chromel-alumel couple. A small steel sleeve is welded longitudinally to the pipe at the point to be measured. The end of the couple, twisted together for about 1/4 in., is placed inside the

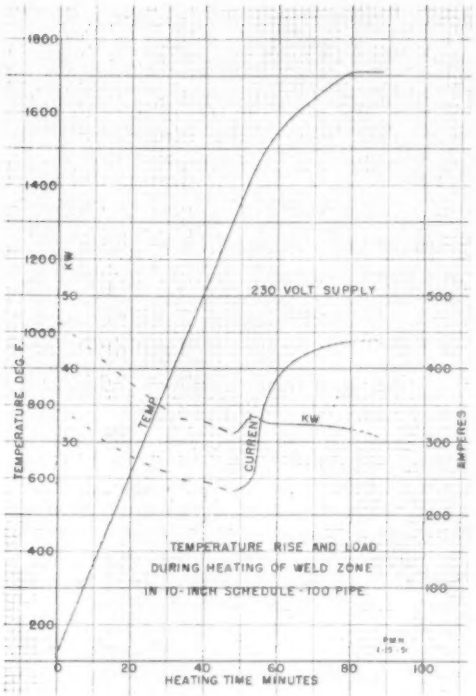

Figure 7

small sleeve and the sleeve is then peened down to grip it. Two feet of the couple extending away from the small sleeve are insulated with ceramic beads, the remainder is insulated with plastic tubing. After each use, a foot of the hot end of the couple is discarded to maintain thermocouple accuracy. Fifty-foot stranded chromel-alumel extension leads connect from the weld zone couples to a terminal block under the instrument compartment. The thermocouple coming from the center of the weld zone is connected through to the recorder-controller. All remaining thermocouples connect to the selector switch on the manually operated potentiometer.

At the start of a weld normalizing operation the operator at the control unit sets the controller at fixed time intervals for successive steps of temperature rise. The temperature rate of rise set by the metallurgist for the pipe alloy involved determines the temperature steps and time intervals between steps. In Fig. 7 the temperature rise curve was plotted as a smooth curve. Actually it consists of a series of steep rises with on-off holding periods between. These periods when the power was not on continuously are shown as dotted lines in the current and power curves. After the weld zone has been held at 1700 to 1725° F. for the prescribed time for normalizing, the operator lowers the temperature in the same fashion in accordance with the requirements of the alloy. During this time he records readings on all thermocouples and the load current and time. This record sheet together with the chart from the recorder are filed as history of the individual welded joint.

Current Welding Literature

(*Continued from page 323*)

Shipbuilding, Riveting vs. Welding. Report on Hogging and Sagging Tests on Riveted Tanker M.V. *Newcombia*. Admiralty Ship Welding Committee—Report No. R.2. H.M. Stationery Office, London (1948), 19 pp., 119 supp. plates, tables $2.25.

Soldering. Flow of Liquid Metals on Solid Metal Surfaces and Its Relation to Soldering, Brazing, and Hot-Dip Coating, G. L. J. Bailey and H. C. Watkins. Inst. Metals—J., vol. 80, pt. 2 (Oct. 1951), pp. 57–76; 6 supp. plates; see also abstract in Metal Industry, vol. 79, no. 19 (Nov. 9, 1951), p. 399.

Soldering. Resistance Soldering Increases Valve Production 25 Percent. Industry & Welding, vol. 24, no. 11 (Nov. 1951), pp. 55–57.

Stainless Steel, Corrosion. Mechanism of Knife-Line Attack in Welded Type 347 Stainless Steel, M. L. Holzworth, F. H. Beck and M. G. Fontana. Corrosion, vol. 7, no. 12 (Dec. 1951), pp. 441–449.

Steel Plates, Cracking. Institution of Engineers and Shipbuilders in Scotland: Presidential Address, A. McCance. Engineering, vol. 172, no. 4473 (Oct. 19, 1951), pp. 502–504, no. 4474 (Oct. 26), p. 540.

Steel. Weldability and Mechanical Properties of Series of Low-Alloy Steels, J. G. Ball and C. L. M. Cottrell. Iron & Steel Inst.—J., vol. 169, pt. 4 (Dec. 1951), pp. 321–336, 3 supp. plates.

Tanks, Welding. "Tanks-a-Million," C. Smith. Welding Engr., vol. 36, no. 12 (Dec. 1951), pp. 30–31.

Timing Devices. Electronic Timers, T. W. Maciejowski. Microtecnic, vol. 5, no. 5 (Sept.-Oct. 1951), pp. 208–224.

Welding, Electric Arc, Inert Gas. Argon Arc Welds in Al-Mg Alloy, T. Morgan. Light Metals, vol. 14, no. 164 (Nov. 1951), pp. 605–613.

Welding, Electric Arc. Manual vs. Automatic Welding, B. J. Smolka and H. Gefvert. Industry & Welding, vol. 24, no. 11 (Nov. 1951), pp. 59–60.

Welding, Electric Arc, Stud. Fundamental Facts About Stud Welding. Industry & Welding, vol. 24, no. 12 (Dec. 1951), pp. 45–47.

Welding, Electric Resistance. Measurement of Electrode Force on Resistance Welding Machines, J. J. Riley. Industry & Welding, vol. 24, no. 11 (Nov. 1951), pp. 40, 42.

Welding. High Quality Production. Industry & Welding, vol. 24, no. 11 (Nov. 1951), pp. 48–50, 52, 67.

Welding Machines, Control. How to Get More Out of Resistance Welding Control, W. E. Large. Steel, vol. 130, no. 4 (Jan. 28, 1952), pp. 68–69, 81.

Welding Machines, Control. Timing Control for Small Spot Welders, M. H. Nichols. Rev. Sci. Instruments, vol. 22, no. 6 (June 1951), pp. 372–373.

Welding Machines, Resistance. Maintenance of Resistance Welders. Sheet Metal Worker, vol. 43, no. 1 (Oct. 1951), pp. 43–45, 94.

Welding the Superalloys, J. Starr. Welding Engr., vol. 36, no. 12 (Dec. 1951), pp. 35–37, 54.

Welds, Grinding. Use of Abrasives in Modern Fabrication. Welding & Metal Fabrication, vol. 19, no. 12 (Dec. 1951), pp. 457–462.

Welds, Testing. Hot-Cracking of Austenitic Welds—with Special Reference to 18/13/1 Cr-Ni-Nb Alloy, E. C. Rollason and M. C. T. Bystram. Iron & Steel Inst.—J., vol. 169, pt. 4 (Dec. 1951), pp. 347–352, 3 supp. plates.

Welds, Testing. Weldment Inspection in Aircraft Construction, J. W. Sweet. Non-Destructive Testing, vol. 10, no. 2 (Fall, 1951), pp. 34–38.

PRACTICAL WELDER AND DESIGNER

Titanium

PRODUCTION of titanium metal is getting into the long-pants stage. To meet vital military requirements, it is being developed at a much faster rate than usual for a newly produced metal.

The world's first small-scale commercial production of ductile titanium metal was started by the Du Pont Co. in 1948. This was in a small unit at the Newport, Del., plant of the Pigments Dept. Rated capacity was 100 lb. a day, but its production did well to run half that much. Now a new plant has been built at the same location which turns out regularly greater-than-ton lots of the metal. Production now is at the rate of $1^1/_2$ tons per day and is expected to get up to $2^1/_2$ tons per day in 1952.

The substantial production increase in such a short time results from continuing research on quality improvement and manufacturing process. Du Pont is currently spending about $1,000,000 a year for research on the metal and ways to make it.

Normally the growth would not have been this rapid because it has not been possible to develop a low-cost conventional smelting process for making it. However, because of the government's urgent demands for the metal for defense purposes, the company scaled up production on the basis of the improvements it had been able to make up to that time. The research program has been speeded up for the same reason.

Strides have been made in the production and melting of titanium, which were in an elementary stage three years ago. However, research to date has not been able to develop the much-sought continuous production process which would provide the key to mass production of low-priced metal.

Although the ultimate goal has not been reached, Du Pont's progress has been substantial. One major achievement was to learn how to make quantities of the metal of good quality and to do it regularly. Another was to develop and build the massive equipment which turns it out in lots of more than a ton at a time—a tremendous quantity considering that the metal was little more than a laboratory curiosity when Du Pont started research on it.

Broad improvements have been made in the manufacturing process itself, although details cannot be disclosed at this time. It still involves a reaction of titanium tetrachloride with magnesium, but differs from that originally used when production was first started.

From the basic work of Wilhelm Kroll, the U. S. Bureau of Mines pioneered and developed the process through the laboratory to the pilot unit stage. This point was reached in the late years of World War II. Du Pont started research on the metal on a sizable basis in 1942 and its work ran roughly parallel to that of the Bureau. The company pioneered commercial production of titanium, bringing in the first small unit in 1948. Research and engineering advances have since transformed the process into a vastly different and larger scale operation.

With these advances in technology and plant capacity, the company finds that production has moved out ahead of the development of uses for the metal; that consumption has not kept pace—probably a temporary situation. As the defense program moves ahead, the demand is expected to go up substantially and require greater capacity. Plans for this are being contemplated now, but there is nothing definite.

Thus far in the development of the metal, Du Pont has been the chief producer. Du Pont's output grew to 55 tons in 1950, the major part of the nation's total—put at 75 tons by the Bureau. In 1951 the company's capacity went up to 600 tons a year with the new equipment. Actual production for the company is estimated at about 400 tons for 1951, out of a total of 700 tons for the nation, as estimated by the Bureau.

This growth was made in four stages. First was the 100-lb. unit. As design was improved and problems worked out, two larger units were installed. All three operated around the clock to boost production. Last April the fourth and biggest unit started into production and is now being brought up to capacity.

Even when this reaches full capacity next year, it will continue to be used partly for experimental purposes. Research on production requires this. Much of the progress up to now has come from pilot-plant experimentation.

The metal as produced by Du Pont is in the form of sponge. It looks like silvery gray coke. Before it can be fabricated, it must be consolidated. But titanium is such a "getter"—it quickly combines with gases in the air at high temperatures—that casting it into solid metal ingots presented one of those "impossible" appearing problems. Once in ingot form, it can be handled readily.

Research teams overcame the difficulties by designing and building two special furnaces at the Newport plant, for induction and for arc melting of the metal by surrounding it with inert gases. The designs

A news release prepared by the Public Relations Dept., E. I. du Pont de Nemours & Co., Wilmington, Del.

have been offered to titanium customers and at least six of them have been put in operation or are being installed by other companies.

Both furnaces at Newport are large enough to approach commercial proportions. In one of them, more than 15 tons of metal have been melted and ingots up to 650 lb. are now being cast. The mere fact of ingot size is considered of primary importance in the industry and the growth from the first 10-lb. ingot—itself a major achievemnt in the field—has been watched with much interest. Major scientific and engineering problems were posed in the research for methods of producing the larger sizes required by fabricators.

The other furnace, based on arc heating, may hold the key to the continuous melting and casting of titanium—one of the factors necessary to mass production of the metal. In it, ingots can be formed continuously from molten metal, then cut to suitable lengths. Furnaces of this type are now producing ingots as large as 1200 lb.

The company continues its research on melting and casting and still does some casting for customers on request. However, the emphasis now is on assisting fabricators to develop their own equipment based on experience and design at the Newport plant.

The company also has done some work on methods of forging, rolling and otherwise fabricating the metal. This knowledge, too, was passed along to the fabricators interested in it.

This broad research activity was necessary because there was relatively little knowledge available on the properties of titanium and methods of handling it and using it. More recently many companies have taken up the work on fabrication and development of uses.

Reduction of titanium ores to metal is chemical in nature and involves chemical operations with which the company is familiar. It also involves raw materials and intermediate compounds which the company has available. Du Pont has a commercial plant in operation for production of titanium tetrachloride. Since 1931, it has produced titanium dioxide on an increasing scale. Titanium dioxide is a white pigment which is used widely in paint, enamel, linoleum, paper and other commonly used things. The continuing research work to improve the pigment led into the scientific investigations which resulted in production of the metal.

As recently as the outbreak of World War I, titanium in any form had no commercial use worth mentioning. In fact, chemistry textbooks published about the turn of the century contained little information about it. It was considered a rare element. Even today it is among the less familiar elements chemically. However, it has been familiar to the mineralogist as a minor constituent or impurity in a large number of minerals. Vast iron deposits long lay idle because of the contaminating presence of titanium. It was the research aimed at finding a practical method for eliminating this "impurity" from iron ore that led to the discovery of the great importance of titanium dioxide as a pigment.

Titanium is a low-density, silver-white metal, between silver metal and stainless steel in color. In ductile form it possesses an excellent strength-weight ratio and exceptional corrosion resistance.

This means that in comparison to such common metals and alloys as iron, copper, silver, steel and brass it is relatively light and that for any given purpose it takes less of titanium than of any of the other commonly used metals to get the same strength. It is readily workable and relatively pliable. Its resistance to corrosion by salt water and atmosphere is much better than that of other commonly used metals and it withstands the effects of most chemicals better than most other structural metals.

Reports and studies up to now indicate that titanium metal will find use in the following fields:

1. Aircraft power plants: Its light weight and strength are needed here and temperatures of operation are reaching higher than aluminum alloys can withstand.

2. Air frames: As speeds increase, air frames must be stronger and operate at higher temperatures. Titanium fits these requirements.

3. Pyrotechnics: Titanium powder burns in air with intense heat. This will probably be a small market.

4. Low titanium alloys: A number of iron and nonferrous alloys use titanium in percentages from 0.1 to 3.5%. The use of high purity metal in these alloys enables producers to get cleaner and stronger alloys with greater regularity.

5. Marine: The unusually fine corrosion resistance of titanium to sea water suggests its use in marine equipment.

6. Chemical equipment: Here again, its corrosion resistance—particularly to oxidizing, chlorine and chloride reagents—brings it into consideration for chemical equipment.

7. Ordnance: Reports have been published that unalloyed titanium is more resistant to projectiles than any armor plate now in existence. If this is substantiated, the metal will be important in this field.

Bibliography

The following information is available on request:

1. Booklet, *Du Pont Titanium Metal*, covers properties and evaluations of titanium.
2. Technical paper, "Arc Melting of Titanium Metal," discusses history and technical developments on melting and casting titanium.
3. Memo, "Titanium the Common Rarity," informal summary of the development and production of titanium dioxide pigments.
4. Memo, "Ilmenite," a report on the ore from which titanium is taken.

Safe Devices for Handling Cylinders

by J. C. McMills

ROUGH handling can cause serious damage to oxygen and acetylene cylinders—and more important, to fingers and toes. Sure, cylinders are safely and strongly constructed, but they still should be handled carefully to prevent knocks or falls.

Every shop should use devices for handling cylinders. Devices such as trucks or stands will not only prevent damage to the cylinder but will also prevent crushed fingers and toes that are painful and costly.

Although cylinder problems vary depending on circumstances and locations, here are several good ways to handle cylinders. They all make cylinder handling easier for the operator. Some of the things shown can be purchased. But all of them can be made from materials that are easily obtained—usually from worn or obsolete equipment or from the scrap pile.

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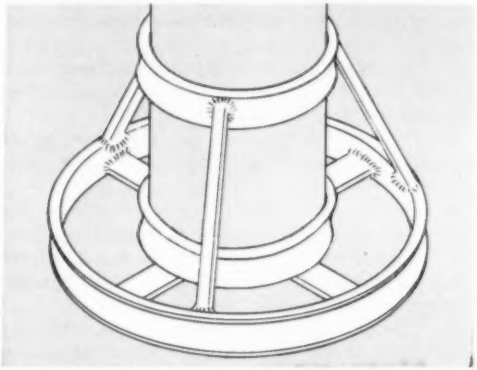


Fig. 1 Make this one from an old wheel rim, cross-braced with strap iron. Slip the cylinder into place through the rigidly braced upper and lower collars

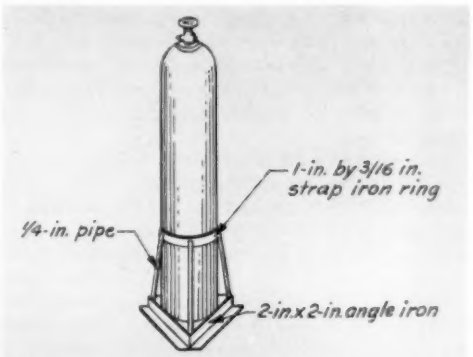


Fig. 2 The base is a triangle welded from 2-in. angle iron. Weld three pieces of ¼-in. pipe to each corner of the triangle and to a 1-in. ring

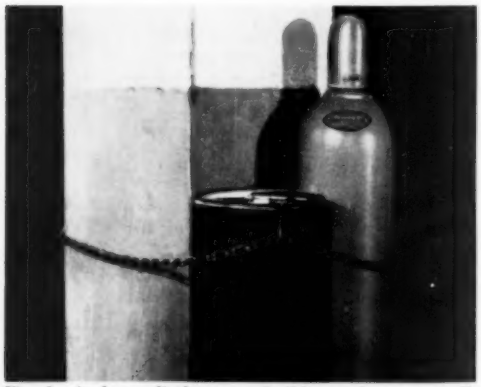
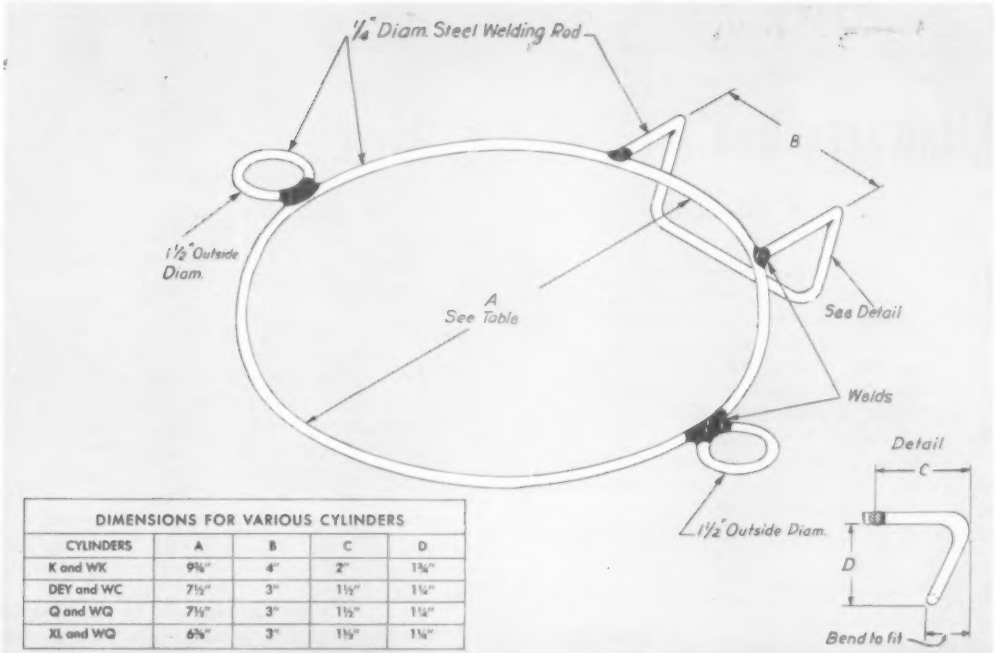


Fig. 3 Anchor cylinders to a building column or wall. A hook over the top edge of the acetylene cylinder keeps the chain from slipping down

Fig. 4 If there is no stationary object to which cylinders can be anchored, chain the cylinders together to make them more steady



DIMENSIONS FOR VARIOUS CYLINDERS				
CYLINDERS	A	B	C	D
K and WK	9⅛"	4"	2"	1⅝"
DEY and WC	7½"	3"	1½"	1¼"
Q and WQ	7½"	3"	1½"	1¼"
XL and WQ	6⅞"	3"	1½"	1¼"

Fig. 5 Heat and shape steel rod to form this clamp. Do not shape the rod on the cylinder. Chain one of the eyes to a pipe or other support and the cylinders will stay upright

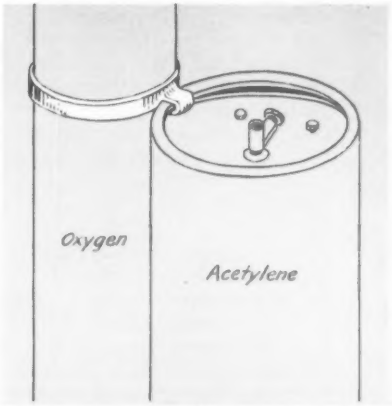


Fig. 6 A strap iron with a lug welded to one side makes a good clamp. The lug fits over the edge of the acetylene cylinder

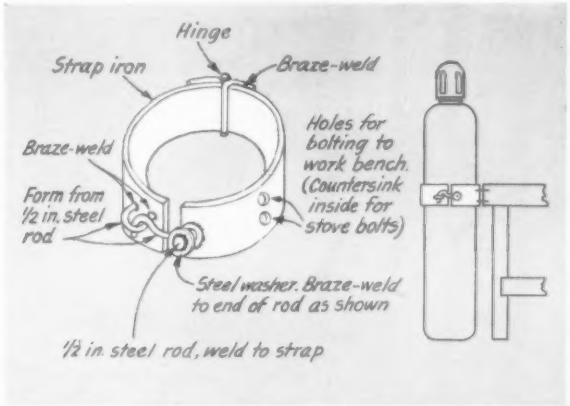

Hinge
Strap iron
Braze-weld
Holes for bolting to work bench. (Countersink inside for stove bolts)
Braze-weld
Form from ½ in. steel rod
Steel washer. Braze-weld to end of rod as shown
½ in. steel rod, weld to strap

Fig. 7 This simple clamp will prevent cylinders from falling while being used. With the clamp bolted to a work bench, cylinders will never topple over

Kilowatts Don't Weigh Anything

by W. P. Brotherton

ONLY recently has spot welding attained top billing in the aircraft industry. Although long regarded as a promising performer, it suffered from a prima donna complex which handicapped its extended use. Inaccurate timing spoiled its execution. Insufficient current capacities and pressures limited its application to small, secondary components and thin-gage materials.

Working in close liaison with production companies, the welding machine manufacturers have overcome these former frailties. Modern equipment is now engineered to fabricate primary, load-carrying aircraft structures and heavy-gage metals of practically every kind. Ryan is securing spot-welded joints in stainless steels that are 100% efficient compared with an average of 60% efficiency for riveted joints.

The new tools squeeze sheets together with a force of 9100 lb. and can "fire" 120,000 amp. across a short circuit. This potent power can stitch together two sheets of $^1/_4$-in. thick steel or two sheets of aluminum alloy $^1/_8$ in. thick.

The control individually delineates the periods allowed for squeeze, weld, forge and off phenomena and cramps the whole cycle within a half-second of time, at the rate of 120 spot welds per minute. These controls "think" and act in terms of thousandths of a second (milliseconds). They prove that the development of the electronic tube gave spot welding its present importance.

W. P. Brotherton is connected with the Ryan Aeronautical Co., San Diego, Calif.

Fig. 1 — Ryan builds large quantities of high temperature jet engine components including these combustion chambers for the General Electric J-47 jet power plant. These vital parts are fabricated from inconel metal and seam and spot welding are used to join the assemblies

A good example of the type of product which is now possible with present spot-welding know-how is the huge external wing fuel tank which Ryan is building in quantity. Largest of their type ever produced, these torpedo-like containers depend upon spot welding for their lightweight design and aerodynamic smoothness. They are fabricated with seam-welded joints in which rotating electrodes produce a series of overlapping spot-welds to form gastight seams without the need for sealing compounds. Not a single rivet head mars their sleek exterior.

Not long ago, spot welding would not have been considered for building such primary structures as floor beams for cargo aircraft. Today, Ryan is making complete sets of 49 floor beams for each big Boeing C-97 Stratofreighter—cargo carrier of the Air Force which can transport 68,000 lb. of freight. One thousand spot welds are placed in each I-beam assembly to form one of the lightest and strongest aircraft members.

In the jet engine field, Ryan uses generous amounts of spot welding to form combustion chambers and transition liners of Inconel and cone and tail-pipe assemblies of stainless steel. The stainless steels and nickel base

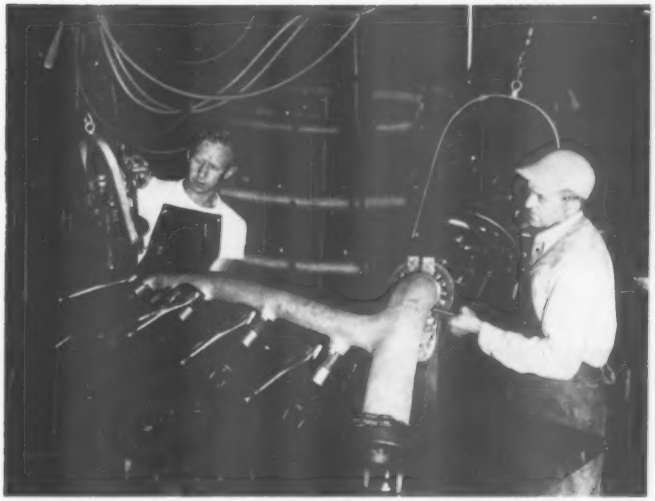


Fig. 2 Ingenious twin spot-welding guns are used on the Ryan production lines for Pratt and Whitney reciprocating engine exhaust systems. Suspended by overhead monorails these spot-welding guns can be moved up and down the assembly lines. They are suspended from spring-loaded reels, which accommodate their weight, and powered by water-cooled cables

Fig. 3 Like sections of a big torpedo, these smooth fuel tank sections are being assembled in the Ryan final assembly department. Completely seam welded into one continuous, smooth surface, the exterior of this tank has no rivets to mar its aerodynamic cleanness

alloys are well fitted for spot-weld design because their high electrical resistance makes short heating time possible. Operating at elevated temperatures, these jet components are vital parts whose failure could cause the loss of an engine and aircraft. Use of spot welding in these military applications is a high tribute to its modern acceptance.

Some of the production benefits derived from the latest electronic controls are:

Slope Control: In which the already brief period, during which the firing of the welding current occurs, is further regulated so that the inrush of current is momentarily dammed and then allowed to build up in a crescendo. By this split-second restraint, added time is provided to permit the welding heat to be better absorbed by the metal surrounding the spot weld. This avoids the "splash," or explosion, of hot metal from too sudden heating. With slope control, it is possible to place larger spot welds in smaller areas and to place them very close to outer edges—giving designers greater latitude.

Tailing Heat Control: This refinement is a controlled diminution of current amplitude after welding to obtain a retarded cooling of the metal and prevent shrinkage cracks. Particularly valuable in the fabrication of aluminum alloys, which tend to cool quickly, this innovation allows the current to die down gradually in a few hundredths of a second.

Preheating and Postheating Control: By arranging for a reduced heating current, immediately prior to welding current, it is feasible to preheat thick-gage metals and allow the electrodes to seat better and also permit the spot welding of these heavy materials with lower currents. Postheating technique is employed to ingeniously temper spot welds in heat-treatable steels without recourse to time-consuming furnace procedures. This precise control of the current after welding is designed to cause sudden cooling, to quench the metal, and then a reduced heating is applied to draw, or temper, the spot welds and give them added strength.

Half-Cycle Firing: With the new electronic controls, Ryan engineers can harness fractional cycles from the 3-phase, 60-cycle line current in the plant. By timing the firing of the welders to occur on half-cycles, extremely short heating currents can be planned. These fractional firings are useful for spot welding thin-gage aluminum alloys which require high-current, short-time values.

Plus or Minus Cycle Firing: Ryan engineers have gleaned another advantage, which the new controls make possible, in this technique. By tapping the welding current wave on alternate plus or minus cycles, a unidirectional spot weld can be made which is uniformly off center. In welding sheets of different

Fig. 4 Operator at Eagle Signal Corporation, Moline, Illinois, uses a General Electric Type WP inert arc welder to weld together aluminum traffic signal controller cabinet

thicknesses, this dislocation can be designed to occur so that the spot welds are cast deeper in the thicker sheet, to maintain uniformly strong adherence.

These are only a few of the new possibilities which can be realized when modern spot-welding machines and experienced engineers work together to extend the usefulness of the process. Spot welding is on the march. If the recent years are a guide to the future, it will continue to take over more and more of the metal joining jobs which are being accomplished by other methods. After all, kilowatts are clean, quick and controllable and they just don't weigh anything.

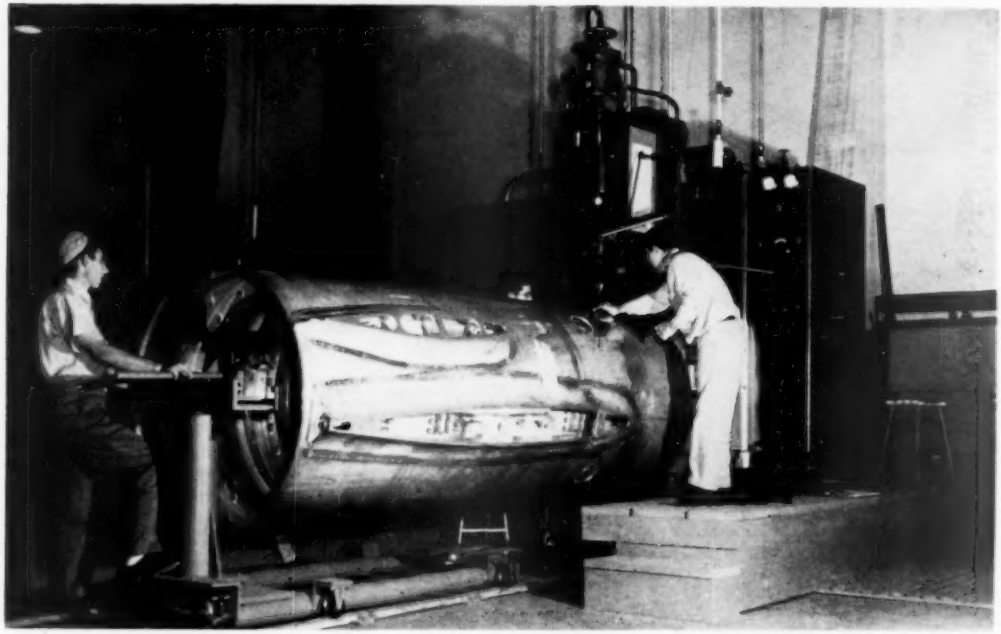


Fig. 5 Huge new Federal seam welding machine, largest of its type, is employed to seam weld large external fuel tanks for aircraft. Eight of these machines are used to build these mammoth tanks which are the largest ever designed

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Refinery Welding

by C. G. Herbruck

C. F. BRAUN & Co. have been serving the petroleum and chemical industries for over forty years with consulting-engineering and research service, a world-wide construction service and by manufacturing specialized apparatus and products. Braun engineers, designs and constructs complete refineries and chemical plants of all kinds. They have built over 300 such refinery and chemical units here and abroad.

Welding has been the "life blood" of their fabricating methods, both in their Alhambra, Calif., plant and in the field on construction sites. A recent job was the fabrication and erection of a Standard Oil Co. refinery near Bakersfield, Calif. An interesting welding application here was the field pipeshop.

Until eight years ago, Braun manufactured all pipespools in their factory at Alhambra, or they farmed the work out to pipespool fabricators. Then, the Company took a turn at fabricating pipespools right on the job sites. Results were good, even though the work at that time was done in temporary shelters without detailed planning. The problem of coordinating the design, the materials, the fabrication and the construction was simplified. And too, field fabrication saved erection costs.

C. G. Herbruck is Assistant to the Secretary of The Lincoln Electric Co., Cleveland, Ohio.

Fig. 2 Roundseam weld. Welding ell to straight section in an 8-in. spool. Units are welded inside the pipeshop and then field erected at refinery in background. A semi-automatic was used to good advantage on pipe welding including flanges. The field pipe shop worked out well on the Stanocal job.

Fig. 1 Preheating an alloy pipespool before welding. Chrome fitting in positioner is heated to 600° by a natural gas heater during welding operation. An E502-15 type 1/8-in. rod is used. Tempilstiks® used to determine heat for this critical material. Welding operations were handled in pipeshop located at job site

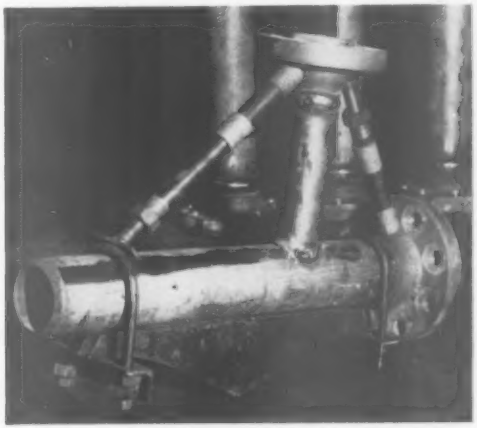

Fig. 3 Setting up a pipespool in the field pipeshop. This is a simple method of aligning fittings to be used on the nearby job. A strong back is used on the bottom with adjustable pipe brace which can be set to predetermined degree and kept in correct alignment during welding operation

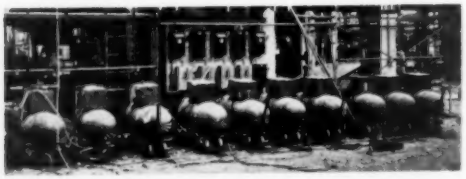

Fig. 4 Bank of 300-amp. welding machines at base of new cracking plant on Stanocal's refinery expansion job at Oildale, Calif. Single electrical panel board shown reduced the hazard of high voltage wiring throughout the plant

Braun then began to improve their embryo field-shops. The temporary buildings gave way to steel buildings, and the equipment and tools were bettered. The pipeshop at Bakersfield was equipped with an electric overhead crane, floor-operated. In addition, there were jibcranes with electrical hoists, contour pipecutters, weld-positioners and many other facilities essential to efficient work.

At Bakersfield a week's work at a time was laid out material-wise in the pipeshop—all the fittings, flanges, weld-ells and so on. The spools moved from the set-up

Fig. 5 Welding 6-in. flange to elbow at the valve on Stanocal's refinery addition near Bakersfield. A 5/32-in. rod was used; 150 amp., 80 v.

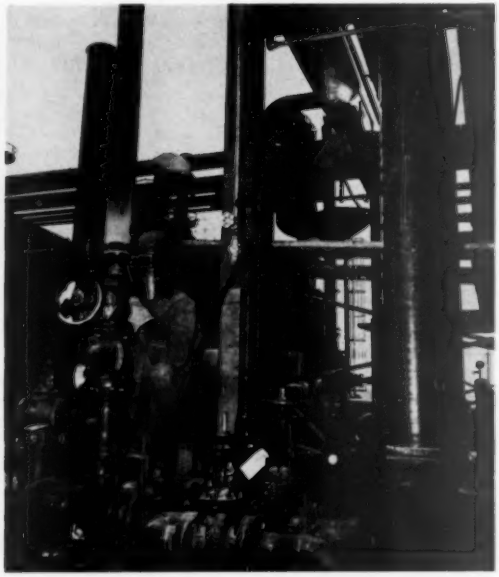

Fig. 6 Field welding on Stanocal's Oildale Refinery. Pipe sections are fabricated in nearby pipeshop and field welded in place. Foreground—Welding swedgenipple to straight section. Above—Welding roundseam between elbow and straight section

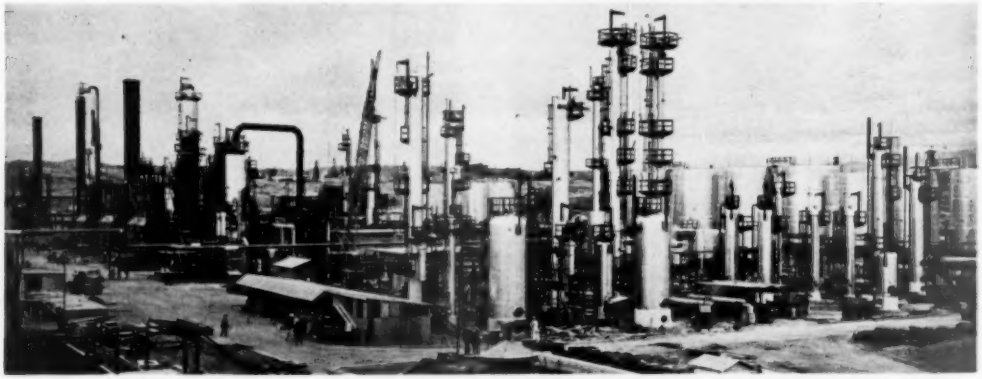

Fig. 7 Over-all view of new refinery addition at Stanocal's property near Bakersfield, Calif. Fabricating pipespools on the job site saves erection costs and makes for production flexibility giving piping crews the spools they needed when they needed them

table to the weld section in an orderly manner. This fieldshop made for production flexibility. When pipe fabrication for one area of the job was halted for any reason, spool fabrication for another area began at once. The piping crews had the spools they needed when they needed them.

Welding Sequence Prevents Distortion

by F. C. Geibig

WHEN three spokes of a cast-iron sheave cracked under heavy loading, welding was used to repair the breaks. But the welding job had to be done carefully or heat distortion would have ruined the sheave. The job was done by braze welding, and a definite welding sequence was followed to avoid distortion. Here is how the job was done.

First the breaks were veed, and then the welding areas were thoroughly cleaned. A stiff wire brush was used for the cleaning job. After being wire-brushed the entire sheave was pre-heated to 450° F. Then a gas ring burner was kept burning beneath the sheave during welding to keep the part heated.

Then the welding sequence was planned. The three broken spokes were adjoining and only one—the middle spoke of the three—was completely cracked. It was decided to weld the completely cracked spoke last. In this way the heat from the welding would keep the cracked sections of the spoke separated, and the pressure that could cause distortion would be relieved.

As each spoke was welded it was first heated to a dark red. Then both sides of the crack were welded before the operator moved to the next spoke. After the third and largest crack was welded the operator played his flame over the three welds, heating them evenly. Then the sheave was covered with asbestos paper and allowed to cool slowly. There was no distortion when the sheave cooled, and it was put back on the job. The repair made the sheave stronger than ever.

F. C. Geibig is connected with The Linde Air Products Co., Newark, N. J.

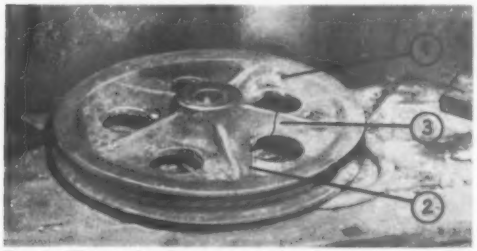

Fig. 1 This is the sheave, ready for the repair job. The hose for the gas ring burner is visible to the right of the sheave. Spokes were welded in the order 1, 2, 3

Fig. 3 The three breaks have been repaired, and the sheave cooled slowly under asbestos paper. There is no distortion, and the sheave is ready to be put back to work

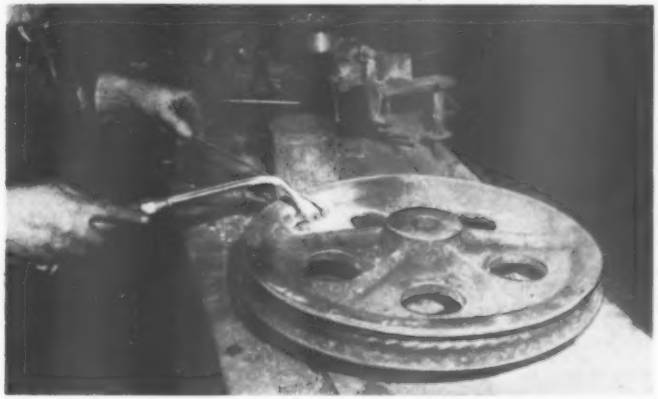

Fig. 2 The operator is starting to weld the first partially cracked spoke. The sheave has been cleaned, then pre-heated to 450° F.

Hard-Facing Spiral Surfaces

by G. E. Kabacy

HARD FACING of screw conveyors, augers and post-hole diggers is a necessary step to prevent flight edges from wearing down and becoming untrue. Particularly in the case of screw conveyors, worn edges permit material to pass between the blade edges and the trough, thus reducing effectiveness of the conveyor. Worn edges can be rebuilt to size with steel rod first.

Hard facing of these edges takes only a short time and should be done before the equipment is put into use. Normally it will extend the life of the equipment from two to six times and, in some cases, may even exceed that. The hard-facing material, as shown in the illustrations here, should be deposited on the sides or radial faces as well as on the peripheral edge of the blade. A normal deposit should be about $^1/_{16}$ in. thick. Be sure to use a good hard-facing rod.

HOW TO HARD FACE

To hard face, first adjust the blowpipe to give an excess acetylene flame. For the right adjustment, the acetylene feather should be approximately $2^1/_2$ times as long as the inner cone.

In hard facing, it is important that the base metal be heated to the sweating point rather than to the molten point. If the metal is molten, the deposit is diluted with the base metal and is not as effective.

Heat the base metal with the blowpipe until it begins to get glazed or watery. When it reaches this state, it is said to be "sweating" and is ready for the hard-facing rod. Withdraw the flame enough to insert the rod between the tip of the inner cone and the sweating surface. As drops of hard-facing deposit form on the surface, remove the rod and spread the deposit with the flame. Normally, the puddle will move easily—do not try to push it or guide it with the rod. If it does not move freely, chances are that the metal is not hot enough or the surface may be dirty. In the latter case, the metal can be cleaned with a file or wire brush.

G. E. Kabacy is connected with The Linde Air Products Co., Buffalo, N. Y

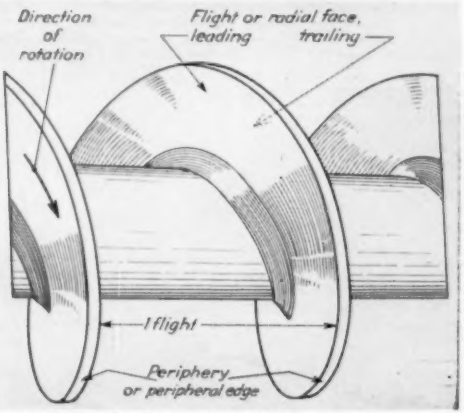

Fig. 1 Normally the peripheral edge is the surface exposed to the greatest wear. However, the leading radial face should also be hard faced if the conveyor is used to transport abrasive materials

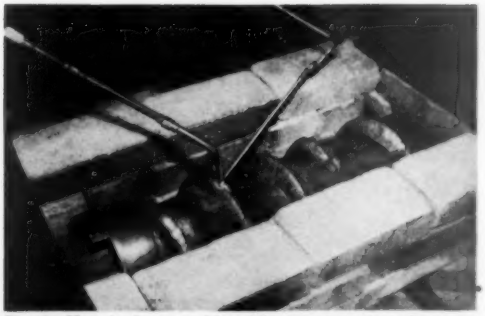

Fig. 2 Here is the actual hard-facing operation of a screw conveyor. The work is preheated and protected by fire brick. Hard-facing rod is deposited along the entire leading edge first and then along the peripheral edge

Fig. 3 A post-hole digger is undergoing treatment here. The leading edge is hard faced for an area of approximately one inch from the edge. The peripheral edge will be hard faced next

the AMERICAN WELDING SOCIETY

activities • related events

Memorial Resolutions

The following memorial resolutions were approved by the Board of Directors of the AMERICAN WELDING SOCIETY at their Jan. 23, 1952, meeting.

William W. Reddie

Resolved, That the AMERICAN WELDING SOCIETY records with profound sorrow the untimely death on July 27, 1951 of its member and colleague, William W. Reddie, who during the past thirty years gave unstintingly of his time and energy to the advancement of the SOCIETY and the welding industry.

His deep understanding, willing cooperation and friendly nature endeared him to his many friends and associates. His foresighted approach and determined nature overcame the most difficult obstacles and made possible many advancements in the field of welding.

During his long and eventful career, he showed boundless energy and enthusiasm in the promotion and application of Arc Welding in all its phases. He was one of the organizers and a past Chairman of the Pittsburgh Section and served notably as chairman and member of many committees for the AMERICAN WELDING SOCIETY.

Resolved, That the AMERICAN WELDING SOCIETY acknowledges the loss of an outstanding engineer and associate and expresses its sincere sympathy to the family and the many friends and colleagues of William W. Reddie.

Prepared by Special Committee
C. H. JENNINGS, *Chairman*
J. P. COUGHLIN

W. W. Barnes

Resolved, That the Board of Directors of the AMERICAN WELDING SOCIETY learned with sincere sorrow of the death of its member, W. W. Barnes, which occurred at his home in Byrn Mawr, Pa., on July 24, 1951.

Resolved, That it is the sense of the Board that the SOCIETY has sustained a great loss. He was a charter member of the SOCIETY and one of the organizers of the SOCIETY's first Section, the Philadelphia Section. He worked for the SOCIETY's best interests and, throughout his lifetime, he gave generously of his ability and time in the interest of the SOCIETY. Even after his retirement from active business he accepted and brought to successful conclusions many SOCIETY projects. He was a friend of all his associates, a man of high ethics, and a welcomed companion to all who knew him.

Resolved, That these Resolutions be spread upon the records of the Society and a copy be given to his family.

Prepared by Special Committee
R. D. THOMAS, *Chairman*
H. W. PIERCE
T. M. JACKSON

Third Annual Welding Conference

A broad-gage inquiry into all aspects of present-day modern welding techniques and problems characterizes the program, just released, for the third annual Welding Conference at Detroit on April 16th, 17th and 18th.

Meetings at Rackham Memorial Building will be addressed by a score of experts in different fields. In addition, exhibits of welding equipment are being arranged. These meetings are under the sponsorship of three technical groups, the American Institute of Electrical Engineers, the Detroit section of the AMERICAN WELDING SOCIETY, and the Industrial Electrical Engineers Society of Detroit.

The program, as announced by E. J. Limpel, A. O. Smith Corp., Milwaukee, includes the following papers:

Wednesday, April 16th—Morning Session—QUALITY CONTROL

"Elements of Quality Control in Spot-welding Aluminum for Aircraft," by F. H. Matthews, Boeing Airplane Co., Seattle.

"Military Aeronautical Spot and Seam Welding Specifications," by J. Maltz and N. E. Promisel, Dept. of the Navy, Bureau of Aeronautics, Washington.

"Industry's Answer to ANW Specifications," two discussions, by P. F. Parks, Solar Aircraft Co., Des Moines, and F. Brandt, Thomson Electric Welder Co., Lynn, Mass.

Wednesday, April 16th—Afternoon Session—INSTRUMENTATION

"Resistance-Welding Instrumentation—Past, Present and Future, as Applied to Quality Control," by Reidar P. C. Rasmussen and Robert McMaster, Battelle Memorial Institute, Columbus.

"Instruments to Improve the Operation of Single-Phase and Three-Phase Resistance Welding Machines," by William R. Stern, Brush Development Co., Cleveland.

"New Devices for Measurement of Welder Voltage Drops on a Power System," by V. H. Kraybill and R. E. Young, Public Service Co. of Northern Illinois and M. Fisher, Jr., University of Illinois.

"Spotweld Monitoring by Resistance Change," by Herbert D. Van Sciver, The Budd Co.

"Electronic Control for Monitoring the Resistance Change During a Spotweld," by S. S. Barnhart and W. B. Hills, General Electric Co., Schenectady.

Thursday, April 17th—Morning Session—POWER SUPPLY

"Introductory Remarks," by E. L. Bailey, Chrysler Corp., Detroit.

"Ratings and Characteristics of Resistance Welding Machine Load," by W. G. Bostwick, Precision Welder & Machinery Co., Cincinnati.

"Power Supply for Resistance Welding Machines—the Power Company's Viewpoint," by H. W. Tietze, Public Service Electric & Gas Co. of New Jersey.

"Synopsis of Users Section—Information for Power Users," by W. K. Boice, General Electric Co., New Haven, Conn.

"Typical Installations," by C. E. Pflug, Nash-Kelvinator Co., Kenosha, Wis.

Thursday, April 17—Afternoon Session—RESISTANCE WELDING

"Up and Down Slope in Spot Welding," by I. W. Johnson, General Electric Co.

"A New Three-Phase Welding System for Welding of Aluminum," by Van Ness and Hartwig, Westinghouse Electric Corp.

"A New Method of Controlling Platen-displacement vs. Time During Flash Welding," by Prof. E. E. Moyer and Mr. Savage, Rensselaer Polytechnic Institute.

"Problems and Equipment in Aircraft Spot Welding," by J. R. Fullerton, Ryan Aeronautical Corp.

Friday, April 18th—Morning Session—FUNDAMENTAL ARC

"Characteristics of the Tungsten Arc in Argon-Helium Mixtures," by T. B. Jones and Merrill Skolink, Johns Hopkins University.

"Forces of Electromagnetic Origin in the Welding Arc," by W. J. Green, Research Lab., Air Reduction Co.

"High Speed Photography—a Technique for Arc Research," by R. J. Krieger, Ohio State University.

"New Instruments for Studying the Welding Arc," by L. P. Winsor, Rensselaer Polytechnic Institute.

Friday, April 18th—Afternoon Session—ARC WELDING

"Consumable Electrode Arc in Inert Gas," by R. W. Tuthill, General Electric Co., Fitchburg, Mass.

"Arc Welding Process for Making Electrical Connections Between Small Aluminum Wires," by C. R. Dixon and Paul

Dickerson, Aluminum Co. of America, New Kensington, Pa.

"Qualitative Instrumentation for D. C. Arc Welding," by E. H. Wilhelm, Electrical Engineer.

Board of Directors Meeting

The second meeting of the Board of Directors of 1951-52 of the AMERICAN WELDING SOCIETY was held in the Continental Room, Statler Hotel, Washington, D. C., on Wednesday, Jan. 23, 1952, at 10:00 A.M. The following attended:

Members: Chairman, C. H. Jennings, F. L. Plummer, E. R. Seabloom, L. C. Bibber, J. U. Durham, R. S. Green, H. L. Ingram, Jr., A. J. Moses, I. A. Oehler, H. E. Rockefeller, G. N. Sieger, J. R. Stitt, C. B. Voldrich and A. E. Wisler.

Staff: J. G. Magrath, *Secretary*, and F. J. Mooney, *Assistant Secretary*.

Guests: W. Roberts, *Chairman*, AWS Washington Section; R. H. Evert, *Secretary*, AWS Washington Section; H. S. Sayre, Secretary, AWS Maryland Section.

Confirmation Approval

The Chairman called for confirmation approval of letter ballot sent out by the Secretary to all Board members, submitting the recommendations of TAC for appointment of AWS representation on AIEE Committee on Instrumentation and upon proceeding with the printing of "Safe Practices for Welding or Cutting Containers That Have Held Combustibles," the Secretary advising that 20 affirmative letter ballots had been received.

Action: Upon motion, duly seconded, confirmation approval of the letter ballot on TAC recommendations was given.

W. W. Reddie Memorial Resolution

The Chairman read the Memorial Resolution for W. W. Reddie which was submitted by a Committee composed of C. H. Jennings and J. P. Coughlin.

Action: Upon motion, duly seconded, the Memorial Resolution, as prepared, was approved.

W. W. Barnes Memorial Resolution

The Chairman called upon the Secretary to read the Memorial Resolution submitted by R. D. Thomas, Sr., H. W. Pierce and T. M. Jackson for W. W. Barnes.

Action: Upon motion, duly seconded, the Memorial Resolution, as prepared, was approved.

Membership Delinquency Period

The Secretary requested that the Board approve an extension of the member delinquency period one month beyond the period provided in the By-Laws. This procedure was practiced in 1950 and 1951, upon Board approval, and the action resulted in a reclamation of from 50 to 60 members each year.

Action: Upon motion, duly seconded, recommendation that the delinquency period be extended one month beyond the period provided in the By-Laws was approved.

AWS Headquarters' Housing

It was decided that the problem of acquiring funds for relocation of AWS Headquarters and for the acquirement of funds for the successful conductance of numerous other activities, as exposed in the Agenda of this meeting, constituted a major problem of fund acquirement and that any solicitation of funds or appropriation of funds from reserve for this specific activity should not occur at this time, but rather the project should be deferred until such time as sufficient funds for all activities were made available through means of a concerted plan for fund raising.

Action: (*a*) Upon motion, duly seconded, the Board of Directors approved the discharge of the Special Committee on Headquarters' Housing, such to be accompanied by the Board's sincere appreciation to that Committee for its efforts and the statement that the work of that Committee not only had been helpful in their present deliberations, but would be of immeasurable assistance should this project be reopened for consideration in the future.

(*b*) It was moved, duly seconded, and approved that the project of securing other AWS Headquarters' Housing be deferred until such time as adequate funds were made available for financing the project, such funds to be accrued as a result of a fund-raising plan for total SOCIETY activities.

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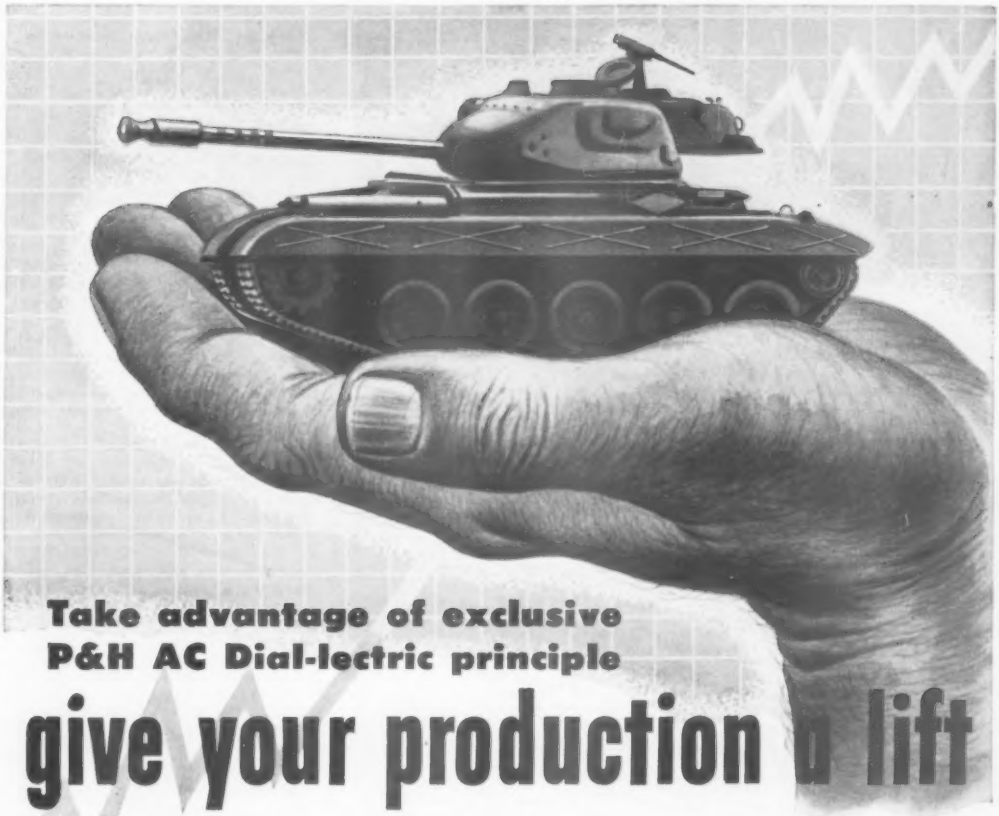

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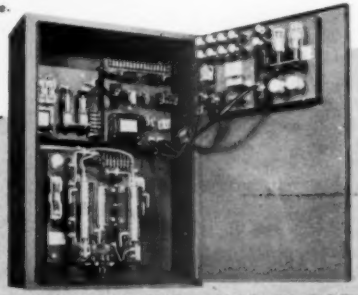

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Fund Raising for TAC

The Secretary was called upon to review this activity. He referred to Agenda Items G, which were distributed to attending members and copies of which are provided for nonattending members. This item dealt with a letter report by the Chairman of the Special Committee on Fund Raising, O. B. J. Fraser, in which he reviewed the activity of the Committee and submitted a letter form to be used as a guide by industrial executives for writing to other industrial executives in other organizations, suggesting that they contribute financial support to the SOCIETY's technical activities, as well as a proposed format for a 6-page brochure to accompany the letter, such brochure reviewing the importance of AWS technical activities to industry, the work done, the work being done, the need for funds to do additional work, and the membership and company affiliations of technical activities' personnel.

Action: (*a*) Upon motion, duly seconded, the report of the Special Committee on Fund Raising was appreciatively received and accepted and the Committee is discharged with a vote of appreciation for its submission, with the recommendation that the Committee be informed that the result of its work will be very helpful in formulating a fund-raising program for all SOCIETY activities.

(*b*) It was moved, duly seconded and approved that fund raising for technical activities be deferred at this time. Further, that the financing of these activities or the necessary replacement of funds in the SOCIETY's Reserve Fund, as withdrawn for these activities, be part of a total fund-raising project.

Membership Promotion Plan

The Chairman called upon the Secretary to further discuss the membership promotion plan which he had submitted under Agenda Item H. The matter of financing the approximate amount of $5000 for this activity, as estimated by the Secretary, was discussed and it was observed that such was not in the SOCIETY's budget for this year. It was decided to proceed with the plan without appropriating additional funds therefor, paying for the progressively developing costs from present operating income and, if necessary at a later date, providing arrangements whereby funds would be made available.

Action: Upon motion, duly seconded, the Secretary's membership promotion plan was accepted and approved.

Welding Educational Foundation

Under this item, which was covered by Agenda Item I, Prof. Gilbert S. Schaller, University of Washington, submitted a letter, dated Dec. 12, 1951, urging that the SOCIETY institute a plan similar to the Foundry Educational Foundation, which was established to interest engineering students in the industry. Prof. Schaller observed that the same sort of thing was necessary in the welding industry and that AWS sponsor a program in which all segments of the welding industry join with the objective of placing welding in the position that it deserves. It was agreed by

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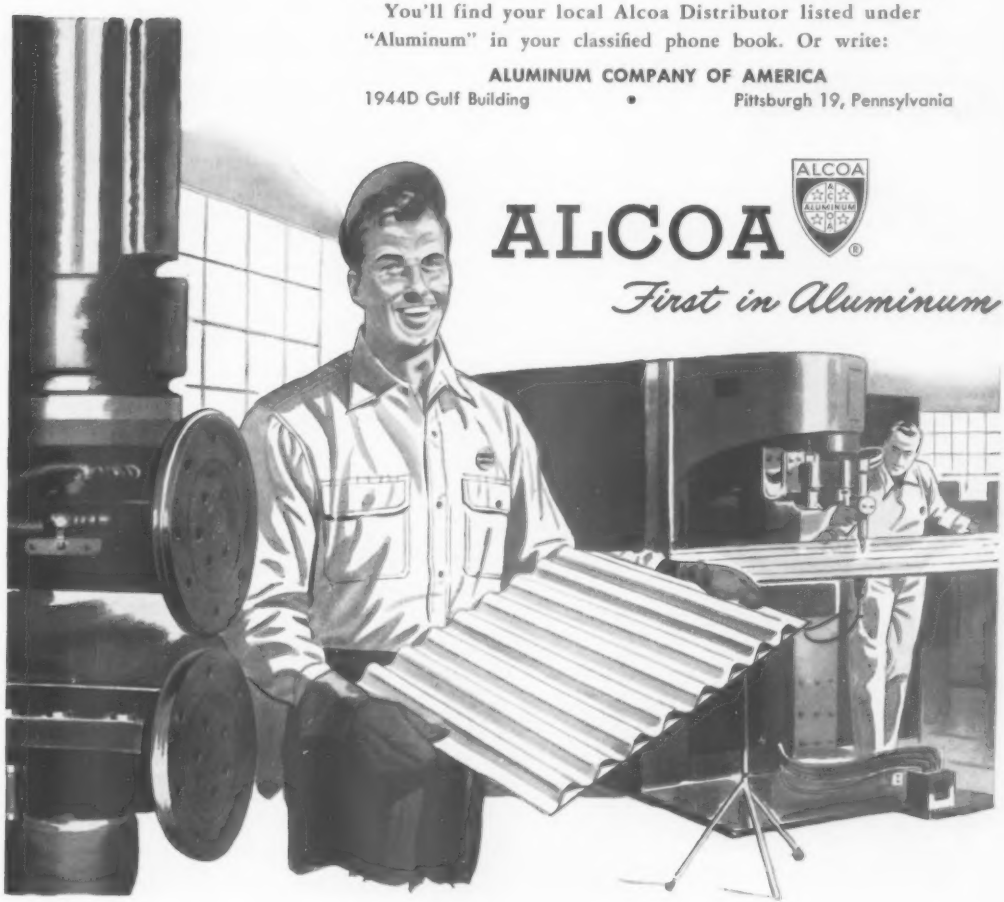

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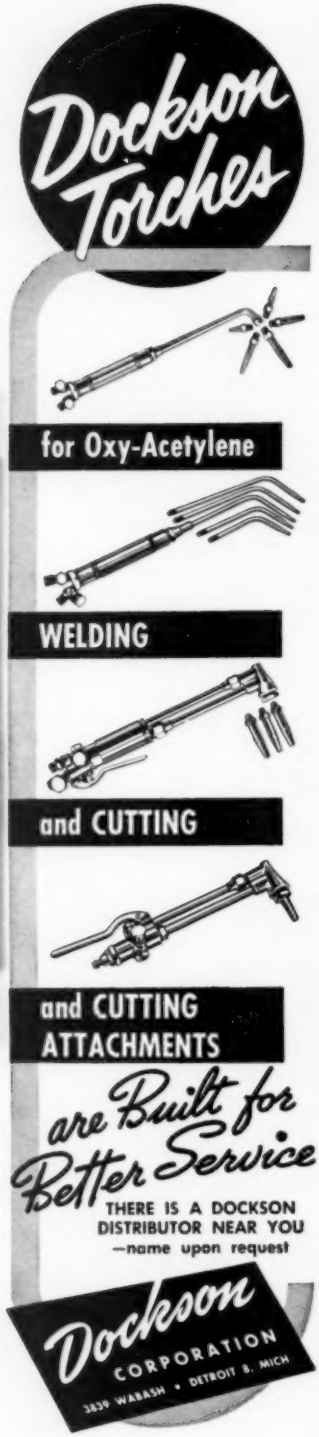

all, including Prof. Green, Board member and Chairman of the Educational Committee, that the proposal had merit. It was also agreed that the present program of the National Educational Committee on the basis of its Vocational Educational Program, as being prepared under the leadership of Chairman A. D. Althouse of the Subcommittee on Education at the Terminal Level, and that the companion program being developed under the leadership of Chairman J. Heuschkel of the Subcommittee on Relations with Engineering Schools, would result in attaining much the same objective. However, Prof. Schaller's proposal well deserved further study and that such study should be given to it by the Educational Committee.

Action: Upon motion, duly seconded, Prof. Schaller's recommendations were referred to the Educational Committee for study and consideration in its over-all program.

Special Publication Committee

The Secretary again asked for favorable action on recommendations that he had made on two previous occasions, that a Special Committee for the handling of sales of books, pamphlets, educational lectures, etc., be organized. He pointed out that the Board had, upon his second previous request, appointed a Special Committee for determining the Advisability of the Establishment of this Committee and that that Committee had reported to the Board that it was advisable to establish such a Committee. However, the Board did not act thereon. The Secretary pointed out that the SOCIETY must now consider a replacement book for *Welding Metallurgy*, ways and means for producing a fourth edition of the *Welding Handbook*, ways and means for producing a series of books on *Welded Design* in the pressure vessel, structural, machinery and other fields, and should produce proper textbooks on welding for colleges. He observed that the rising cost of SOCIETY operation, coupled with the reluctance of the membership to pay higher dues proportionate to that they pay for every other service they purchase, makes it imperative that the SOCIETY seek supporting income from other sources, among which are additional publications, and that a Special Committee should be instituted for handling the sales of books, pamphlets, educational lectures, etc.

Action: Upon motion, duly seconded, the Chairman was authorized to appoint such a Committee.

Vocational Education

The Secretary advised that the Subcommittee on Education at the Terminal Level, a division of the National Educational Committee, prepared a large report which is now under review by TAC for correctness of references to and standards of AWS. Upon final editing, it is proposed that the report be photo offset processed and distributed to some 100 State Educational Consultants (two in each State) for review; then printed in book form and distributed to some 5000 Superintendents of Schools throughout the States with recommendation that the welding educational pattern therein be adopted by their schools. The Secretary estimated that this entire project would require funds to the amount of $10,000. He advised that it was designed to provide uniform adequate welding training of students at terminal level (high schools and vocational schools) with the intent of interesting a certain percentage of them to continue welding engineering study at the graduate level. It was suggested by the Subcommittee that the welding industry equipment manufacturers should be interested in this activity to the extent of, upon solicitation, financing the project similarly to the manner in which the Ford Motor Co. financed the AI-VE Conference book report on "Standards for Automotive Service Instruction in Schools." The Secretary advised that, as Secretary of the National Educational Committee, he was acquainting the Board with this activity, as before requesting the Subcommittee to proceed further with the activity, i.e., the necessarily large task of turning out a completely edited report—the opinions, advice and suggestions of the Broad of Directors were sought. He advised that the National Educational Committee had given its approval of the plan. The Secretary also observed, at this time, that possibly in one year the Subcommittee on Relations with Engineering Colleges, a division of the Educational Committee which is now on preliminary work, will present a project of comparable scale and requiring comparable financing. Their plan is for welding education promotion in the engineering schools. In cross discussion, Prof. Green and Mr. Stitt, Board member who is active in this Subcommittee's work, agreed that the initial job of editing and photo offset processing for distribution to 100 State Educational Consultants would entail a sum of approximately $2000. H. L. Ingram, Jr., District Vice-President, and Washington, D. C., representative of his organization, observed that the U. S. National Office of Education should be interested in these projects and should be approached toward the end of assistance, both in financing and distribution.

As a result of the foregoing review, the Board of Directors was in agreement that the work of the Subcommittees of the Educational Committee are much needed activities but at this time, the SOCIETY does not have adequate funds for initial editing and distribution to 100 State Supervisors. However, this worthy project shall be considered in the over-all financing of the SOCIETY and when funds are available, the necessary initial activity will proceed. The Subcommittees are to be commended for their activity and encouraged therein.

Engineering Societies' Library Donation

It has been customary for AWS to make a contribution each year of $200 to the Engineering Societies Library, located in the Engineering Societies' Building, the headquarters' location of our SOCIETY. The library's services are available to all members of AWS. Letter of Jan. 9, 1952, from the Engineering Societies' Library suggests that, if possible, due to increased costs it would be very helpful if we could increase our contribution this year. In discussion, it was decided that, in view of the necessary activities of the SOCIETY re-

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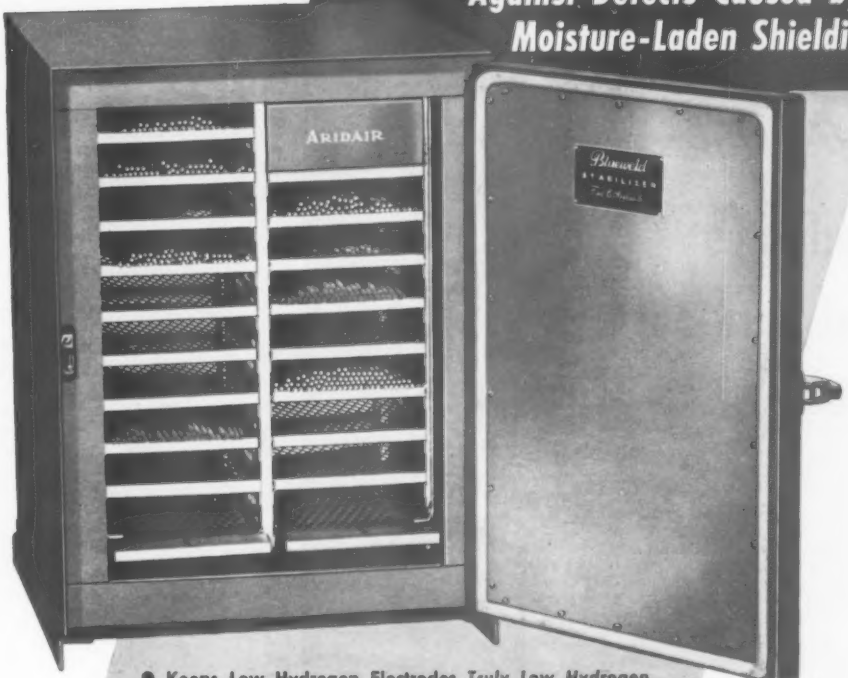

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quiring financing, it would not be possible to increase the contribution.

Action: Upon motion, duly seconded, the regular contribution of $200 to the Engineering Societies' Library for the year 1952 was approved.

Nominating Committee By-Law Amendment

The By-Laws Committee was requested to make changes in the National By-Laws concerning procedures for the National Nominating Committee. The Chairman of the By-Laws Committee submitted a report for his Committee under cover of a letter, dated January 16th, accompanied by attachments, all of which were included in Agenda Item P distributed to attending members, and attached for nonattending members. The By-Law amendment provides for the appointment of a Chairman of this Committee in the year previous to his term of office and the provision that the Nominating Committee shall hold an open meeting at the time of the Annual Meeting of the SOCIETY, at which time members may appear to discuss the eligibility of the candidates for the various offices falling vacant. The attachments call for all provisions for the amending of supporting By-Laws:

Action: Upon motion, duly seconded, proposed amendment, as submitted by the Constitution and By-Laws Committee, met with the approval of the Board of Directors.

Manufacturers Committee Chairmanship

Due to ill health and physician's advice that he must reduce his activities, J. B. Tinnon regretfully presents his resignation as Chairman of the Manufacturers Committee.

Action: Upon motion, duly seconded, Mr. Tinnon's resignation as Chairman of the Manufacturers Committee was regretfully accepted, he to be notified with a letter of appreciation and regret that his health does not permit him to carry on in this activity.

Special Membership Committee Chairmanship

Due to ill health and physician's advice that he must reduce his activities, J. B. Tinnon regretfully presents his resignation as Chairman of the Special Committee on Membership Classification.

Action: Upon motion, duly seconded, Mr. Tinnon's resignation as Chairman of the Special Committee on Membership Classification was regretfully accepted, he to be notified with a letter of appreciation and regret that his health does not permit him to carry on in this activity.

Committee Chairmen Appointments

Discussion was held upon the requirement of filling the vacant Chairs of the Manufacturers Committee and the Special Committee on Membership Classification. It was decided that the filling of these Chairs would require further consideration and exploration.

Action: Upon motion, duly seconded, the President was authorized to submit his selections for Chairmenship of these Committees to the Board of Directors by letter ballot or to the Executive Committee, if the urgency requires and if that Commit-

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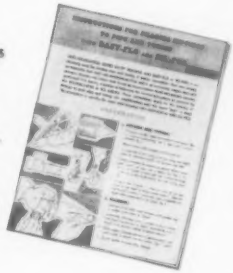
BULLETIN 17

This bulletin gives complete instructions for brazing fittings to pipe and tubing with EASY-FLO and SIL-FOS. It tells—how to cut and fit pipe and tubing—how to clean and flux surfaces to be joined—how to support assemblies—how to heat—how to clean after brazing. It covers the making of vertical up, vertical down and horizontal joints.



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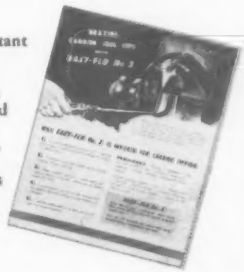
This bulletin gives full instructions for EASY-FLO and SIL-FOS alloy brazing with gas torches—including fit of joint—cleaning—fluxing—assembling—heating—applying the alloy—flux removal after brazing. Ask for the Torch Brazing Instruction Bulletin.

BULLETIN 11-A

This bulletin covers an important item in metal working shops today—the mounting of cemented carbide tool tips with EASY-FLO No. 3 on lathe and milling cutters and other carbide tipped tools and parts. It explains why EASY-FLO No. 3 is recommended for this work by leading carbide tip manufacturers and covers the procedure step-by-step for various heating methods.



BULLETIN 14

This bulletin covers the repair of broken broaches, drills, taps, band saws, circular saws, form cutters and milling cutters of all kinds with EASY-FLO. It explains how, with a few cents' worth of EASY-FLO, valuable tools can be put back in service in a jiffy at a fraction of the cost of replacement.

TECHNICAL BULLETINS

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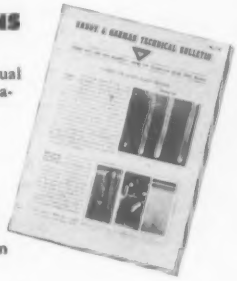

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tee holds a meeting in the interim between now and the next Board meeting.

Over-All Fund Raising

Comprehensive discussion was held on the over-all problem of obtaining funds for conducting the various activities of the SOCIETY as recommended by the various Committees and individuals in so far as those activities were essential to the welfare of the SOCIETY and the welding industry. These activities include the obtaining of funds for expansion of technical activities (this comprehends the automatic replacement of funds which the SOCIETY was authorized to withdraw from the Reserve Fund account to preliminarily finance this project); funds for Educational Committee activities in both the Vocational (terminal level) and the Undergraduate (engineering college) fields; funds for producing additional publications, such as the 4th Edition of the *Welding Handbook*, replacement book for *Welding Metallurgy*, series of books on *Welded Design* in the various industry fields, and books on welding in engineering colleges; necessary funds, if required, for other AWS Headquarters' housing; and other activities essential to the welfare of the SOCIETY and industry. In cross discussion, it was observed that it might be advisable to appoint executives of the welding equipment manufacturers and other organizations to an AWS Fund Raising Committee or organization. In further discussion, it was observed, particularly by Mr. Sieger, that this was a matter that should receive the attention of the Manufacturers Committee in that that Committee, at the Board meeting on Oct. 18, 1951, was authorized to interest itself in all activities of the AMERICAN WELDING SOCIETY. It was further proposed that perhaps instead of the SOCIETY asking directly for funds, that fund raising should be tied in with Sustaining Membership. The Secretary pointed out that this was proposed before in connection with the technical activities' fund-raising activity as originally contemplated, but that the Board of Directors, at that time, stated a preference for direct solicitation for contributions rather than on the basis of Sustaining Membership. The Secretary also observed that the Special Committee on Membership Classification was requested by the Executive Committee, as approved by the Board of Directors, to consider and submit a plan for changing the present "Individual" type of Sustaining Membership to a "Company" or "Organization" type of Sustaining Membership, as it was felt that in this manner industry would be better represented through membership in the SOCIETY and would be in a position to subscribe to Sustaining Membership on the basis of dues higher than the present $150 per unit pattern. It was agreed by all that this program should receive the attention of the Manufacturers Committee and it was proposed that as soon as the President appointed a Chairman of the Manufacturers Committee, as early as possible, the President should request the Chairman of the Manufacturers Committee to call a meeting of that Committee so that the need for a fund-raising program could be submitted to them and their opinions and cooperation secured.

Action: (*a*) Upon motion, duly seconded, it was voted that the President make early appointment of Chairman of the Manufacturers Committee.

(*b*) Upon motion, duly seconded, it was voted that a special meeting of the Manufacturers Committee be called, with Officers of the SOCIETY present, for the purpose of acquainting the Manufacturers Committee with the problem in hand.

(*c*) Upon motion, duly seconded, it was voted that the manufacturers Committee submit recommendations as to whether that Committee should take over this activity, or whether a Special Committee be appointed which would be composed of officers representing all welding equipment manufacturing or other companies.

Weldment Specifications

Upon completion of the business on the agenda, in response to the Chairman's call for New Business, L. C. Bibber advised the Board that as of January 29th an ASTM Committee, or Subcommittee, is scheduled to meet in Philadelphia, its agenda including an item—"Should ASTM write a specification for weldments,"—or equal intent. Mr. Bibber stated that such was the business of AWS and not ASTM; that AWS should have strong TAC representation at the meeting, preferably more than one person, for the specific purpose of op-

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711-23

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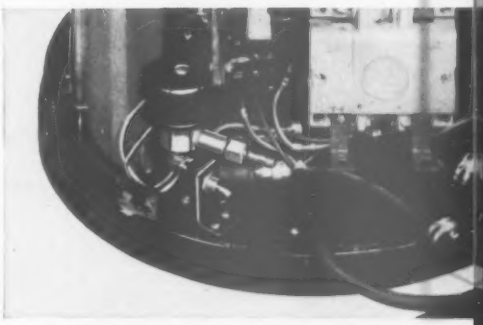


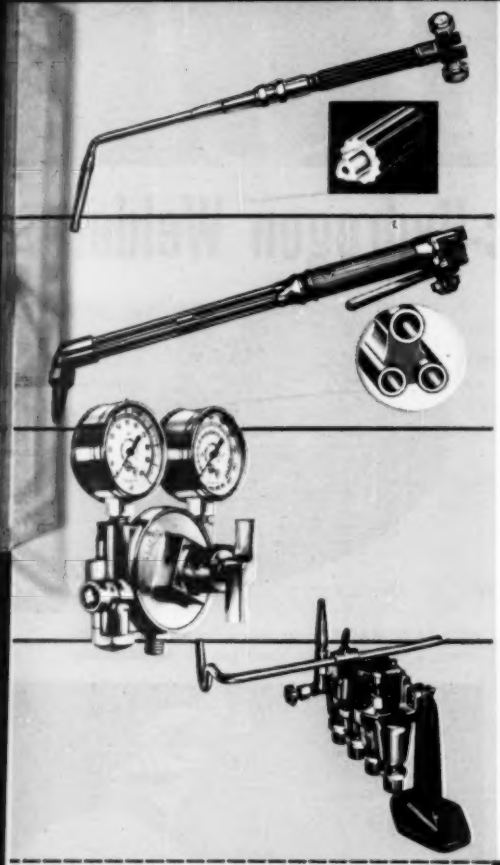
YOU SAVE GAS because this solenoid valve on the atomic-hydrogen welder shuts gas off automatically

THIS $1600 DIE was saved from the scrap heap by a $40 repair job with a G-E atomic-hydrogen welder

YOU'LL GO FOR REGO*

A NAME THAT HAS MEANT QUALITY FOR 40 YEARS

PROVE IT TO YOURSELF—TEST ANY ONE OF THESE 4 BASIC ITEMS



1 Rugged, performance-proved GX Welding Torch

Typical of REGO quality is this widely preferred Welding Torch. Stronger than steel, lighter than brass, the unique GX handle has no tubes, screws or soldered joints. Stainless steel head further guarantees long life. Four handle lengths and a broad variety of free-flow mixers and tips fit the GX to any welding job, regardless of size.

2 Dependable, gas-saving KX Cutting Torch

Thousands of industrial plants, scrap yards, railroads and shops have relied exclusively on this torch for years. Stainless steel head and triangular tube construction make the KX tough and durable. Diaphragm-type valve prevents leaks, provides sensitive control. Tip-mixing stops flash-backs. Available with lever on bottom or side, and with 75° or 90° heads.

3 Precise, balanced-action Two-Stage RegOlator

The regulator that has won fame for accurate delivery of all types of industrial gases! Its two stages combine stem-type and nozzle-type design to assure delivery of unvarying working pressures. Running back and forth from work to regulators for adjustments is eliminated. A point-by-point comparison will quickly establish the excellence of the REGO RegOlator.

4 Redesigned, improved REGO Economizer

This time-proven money-saver is even more efficient now. New 90° lever permits welding torch to hang with tip toward pilot flame. New pilot is aspirator type, providing longer and more stable flame. To relight the torch at its previous flame setting, just lift from lever hook; to extinguish, replace on hook. This is the automatic shut-off that has saved innumerable hours of welding production time.

NATIONAL CYLINDER GAS COMPANY
840 N. Michigan Ave., Chicago 11, Ill.
Rush me catalog and price list on REGO Outfits and Apparatus, for welding and cutting.

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NATIONAL CYLINDER GAS COMPANY
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*T. M. of the B. B. Co., Chicago

"Red Head"
WELDING CLAMPS
• Designed for Welding •
No Threads To Damage

1. Case Hardened threads are always protected from weld spatter and never exposed to damage in open or closed position.

2. The clamp body is cut from solid plate, thereby insuring extreme rigidity and giving great resistance to bending or twisting.

3. Heat treated chrome molybdenum alloy handle offers great resistance to bending.

23 stock sizes

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posing any move by ASTM to include such activity in their program. The Secretary advised the Board and Mr. Bibber that immediately following the Secretary's receipt of the same information, such having been transmitted to him by Mr. Bibber by telephone about eight days previous to this meeting, he wrote the Chairman of TAC, relaying Mr. Bibber's information and opinion, and endorsing Mr. Bibber's opinion, with copy to Mr. Greenberg, Technical Secretary. Further, that Mr. Greenberg planned to attend the stated ASTM meeting.

In the Board discussion following, all Board members present expressed agreement with Mr. Bibber. Further discussion disclosed that all members present were of the firm opinion that preparation and issuance of specifications for weldments was the business of the AWS Technical Activities Committee. Accordingly, the following action was taken:

Action: Upon motion, duly seconded, it was voted that the Board of Directors direct the Technical Activities Committee to include the preparation and issuance of weldment specifications in its program; to provide adequate AWS Technical Activities Committee representation at the January 29th meeting of the specific ASTM Committee involved; and to inform the ASTM and its committee that projects dealing with specifications for weldments are, properly, activities of the AMERICAN WELDING SOCIETY.

Membership Status Report

The Assistant Secretary distributed a membership status comparative report, Dec. 31, 1950, vs. Dec. 31, 1951, to the attending members. It indicates an improvement in both active members and total registration over a comparable date one year previous on the basis of: Active 6280 vs. 6776; Total Registration—7248 vs. 7633; Delinquents—968 vs. 857.

W. Roberts, Chairman of the Washington Section, announced that the Washington Section Officers extended a cordial invitation to the National Officers and Board of Directors to attend the dinner and evening activities of the Washington Section, being guests of the Section, giving time, place, and arrangements for transportation. The Chairman expressed the appreciation of the Officers and the Board of Directors and Acceptance was provided by those Board members attending who could remain over for the evening activities.

Bound Volume 1951

Bound Volumes of THE WELDING JOURNAL for the year 1951 are available in black imitation leather covers, together with a comprehensive subject and authors index. Price $15, including postage.

This volume, comprising a total of 1156 pages in the JOURNAL and an additional 624 pages in the *Welding Research Supplement*, represents a veritable encyclopedia of information in the welding field. Copies may be ordered through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

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Carbide
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PERSONNEL

Claussen Joins Carbide Labs.

Dr. Gerard E. Claussen has recently become connected with the Union Carbide and Carbon Research Laboratories in Niagara Falls, N. Y. From 1942 to date Dr. Claussen was metallurgist for the Reid-Avery Co. in Baltimore. Previous to that he was metallurgist with the Machlett Laboratories, Inc. From 1936 to 1940 Dr. Claussen was Research Assistant with the Welding Research Committee, now known as the Welding Research Council. In association with W. Spraragen he summarized information on most of the important phases of welding in nearly sixty critical digests of the literature. He also assisted the late H. M. Hobart in the operation of the University Research Committee. Dr. Claussen was co-author with Prof. O. H. Henry on the first edition of "Welding Metallurgy" published by the AMERICAN WELDING SOCIETY. During this period Dr. Claussen was an instructor in Metallurgy at the Evening School, Polytechnic Institute of Brooklyn.

All of his friends in the AMERICAN WELDING SOCIETY and the Welding Research Council wish "Doc" every success in his new connection.

D. D. Spoor Appointed Manager

Dale D. Spoor, former chief of the Industries Branch of the Metalworking Equipment Division of NPA, has been appointed manager of Airco's Equipment and Process Sales Department it was announced by H. F. Henriques, Vice-President, Air Reduction Sales Co., a Division of Air Reduction Co., Inc.

Mr. Spoor received his degree in Engineering Administration from Massachusetts Institute of Technology in 1922 and began his career in the welding industry with the construction of an oxygen plant in California in 1928. He served in various capacities in the Airco organization including an assignment in Washington and in 1941 became manager of the St. Louis district. In 1948 he was appointed manager of the newly formed Equipment Sales Department.

In March 1951 Mr. Spoor was granted a leave of absence from Airco to organize the Welding Equipment Section of the Machinery Division of the National Production Authority, and in November 1951 he was appointed chief of the Industries Branch of the Metalworking Equipment Division of NPA.

With his tour of duty at NPA completed, Mr. Spoor has returned to Airco to head a new department which includes equipment sales, arc welding sales, process development and general technical sales, with headquarters at 60 E. 42nd St., New York City.

Poethig Serving on Safety Committee

Robert E. Poethig, Director of Research, The Bastian-Blessing Co. of Chicago has been appointed to the National Fire Protection Association Committee on Gases as representative of the Liquefied Petroleum Gas Association. This committee is the final authority in the establishment of the safety standards for the gas industries.

The chairman of the Committee on Gases under whom Mr. Poethig will serve, is Mr. H. E. Newell, assistant chief engineer of the National Board of Fire Underwriters. The N.B.F.U. also publishes and gives wide distribution to the various safety standards.

Since this committee is concerned with all types of gases, Mr. Poethig's great wealth of experience in the field of compressed gases as well as the LP-Gases should prove particularly valuable. He has been and still is active in the Liquefied Petroleum Gas Association, the Compressed Gas Association, the American Petroleum Institute and the AMERICAN WELDING SOCIETY, being director of the L.P.G.A. and chairman of the Safety Device Committee of C.G.A.

OBITUARY

Otis L. Smith

Otis L. Smith, President of Weldit, Inc., Detroit, Mich., died at his desk on January 28th. He collapsed from a heart attack and almost immediately passed away.

Otis Smith was a welding pioneer, having spent over 35 years in the industry. His original company was the Weldit Acetylene Co., established in 1918, at 638 Bagley Ave., in Detroit. In 1946 he built a new plant at 990 Oakman Blvd., in Detroit. He developed many welding products, notably the Weldimatic torch and the Weldit Gasaver.

He was very active in fraternal and civic life, being a member of several organizations including the AMERICAN WELDING SOCIETY.

Henry Booth

Henry Booth, sixty, Vice-President and Director of Shawinigan Products Corp., died on February 4th, while attending a luncheon at the 71st Regiment Armory, New York City.

Mr. Booth was associated with calcium carbide sales for over 35 years. He entered the field as a salesman for Fairbanks Morse Co. who, at the time had the sales agency for Canadian carbide in the United States. As Fairbanks Morse only handled carbide sales from their New York office, a Canada Carbide Sales Co. was formed with head offices in this city to handle sales west of Pittsburgh. Mr. Booth was sent to Chicago to open a small office in their name, where he operated from 1917 to 1920.

In 1920 the Shawinigan Products Corp. took over these sales activities. From 1920 to 1940 Mr. Booth was Sales Manager. From 1940 to his death he was Vice-President. He was elected to the Board of Directors in 1929.

Mr. Booth was very active in the International Acetylene Association. He was President of this organization for two terms, 1940–42, a Director from 1942 to 1948, and Chairman of the Executive Committee since 1947. Also he served on many committees of the Compressed Gas Association and was similarly active in the AMERICAN WELDING SOCIETY.

A resident of Westport, Conn., for 30 years, he served for a time as President of that city's Chamber of Commerce. He is survived by his wife Mrs. Ava Booth, a son Henry and a daughter, Mary.

Charles Frantz

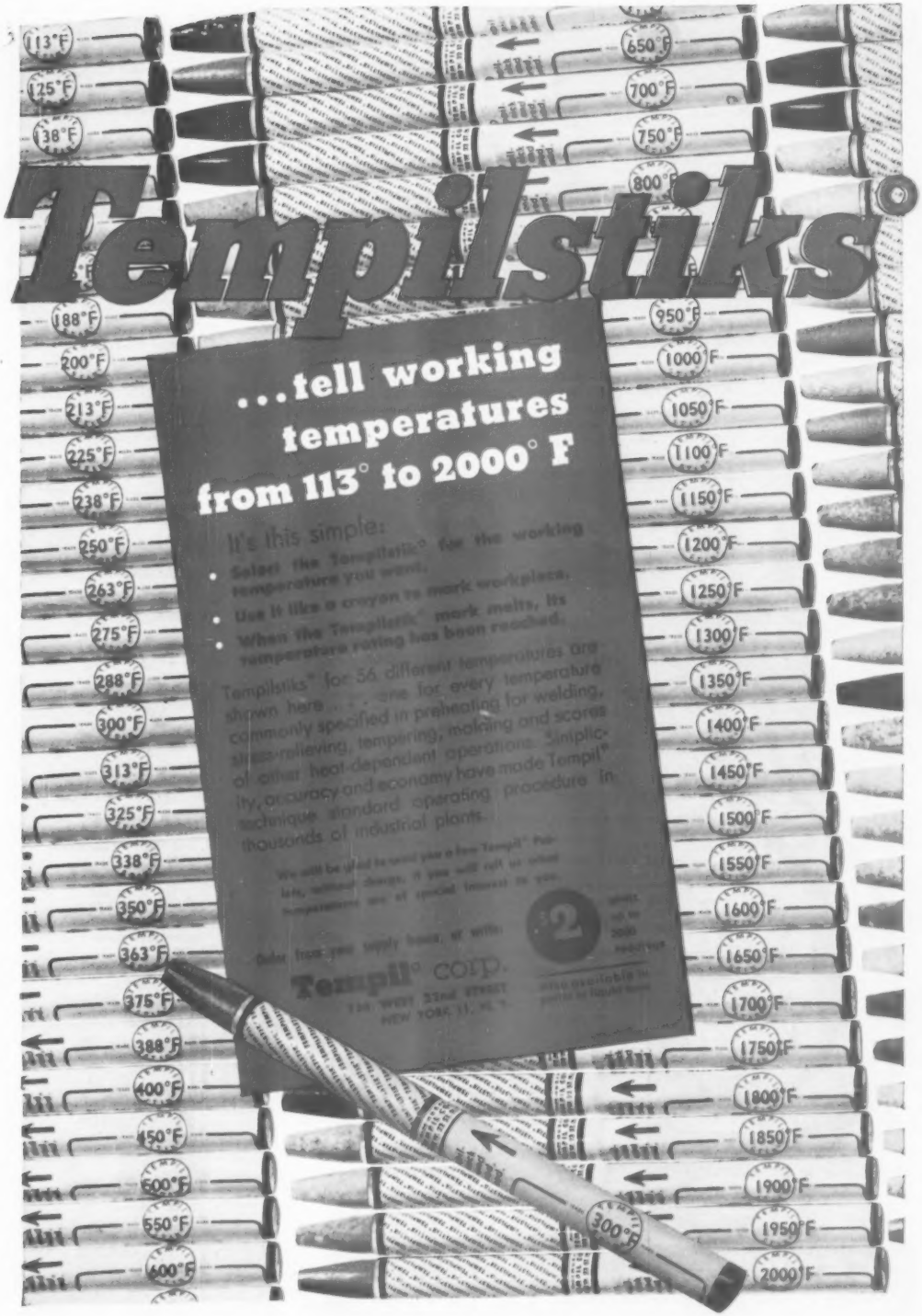
Charles F. Frantz, Chief Estimator for Lehigh Structural Steel Co., Allentown, Pa., died unexpectedly on January 17th at his home, 3118 Oxford Circle.

He was born in Lancaster, but lived in Allentown for the last 30 years, entering employment with Lehigh in November 1921 as a draftsman. In 1935 he was made a squad leader in the estimating department and became chief estimator in 1937.

Mr. Frantz had previously been employed by the American Steel Co. and worked for some time in Cuba. Later he worked in the designing department of Lancaster Iron Works and Bethlehem Contracting Co.

He was a member of the AMERICAN WELDING SOCIETY, Industrial Club, the Chamber of Commerce, the Franklin Fire Co. and the Professional Engineers Club.

He is survived by his wife, Mrs. Sarah Frantz; his father, Daniel Frantz; a son, Jack Leibley Frantz; two grandchildren and two sisters.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...tell working temperatures from 113° to 2000° F
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Templstiks® for 56 different temperatures are shown here . . . one for every temperature commonly specified in preheating for welding, stress-relieving, tempering, melting and scores of other heat-dependent operations. Simplicity, accuracy and economy have made Tempil® technique standard operating procedure in thousands of industrial plants.
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Phillip Kearney

Phillip Kearney died on Dec. 29, 1951, at the age of seventy-five. Mr. Kearney founded the K and G Welding and Cutting Co. (now the K-G Equipment Co.) in 1914. He was president of the business he founded until 1947 when he sold his interest in the organization and retired. He was President of the International Acetylene Association in 1934–35 and a Director from 1935 to 1939.

Ben L. Wise

Ben L. Wise, 47-year-old Director of Production, and a Director of National Electric Welding Machines Co., died Friday evening, February 15th, at Mercy Hospital, Bay City, Mich., after suffering a heart attack earlier in the day. A native of Greensburg, Pa., he was born Jan. 8, 1905, and was presently a resident of Bay City.

Mr. Wise was a graduate electrical engineer of Pennsylvania State College. In 1946 he became associated with National Electric as Production Engineer. Before that he served as Assistant General Manager of Federal Machine and Welder Co., Warren, Ohio.

He was a member of the American Institute of Electrical Engineers, Welding Research Council and American Standards Association. Also, at one time, he was Vice-President of District 4, AMERICAN WELDING SOCIETY. In 1949 he was elected President of the Resistance Welder Manufacturers Association, and in 1950 he was named Chairman of the association's Advisory Board. He was, in addition, a member of Tau Beta Pi, honorary engineering fraternity, and of the Atomic Energy Commission in World War II.

Mr. Wise is survived by his widow, Margaret, his mother and six brothers.

TWECO CABLE CONNECTORS

–"SOL-CON" (solder type)
–"MEC-CON" (mechanical)

Quick-detachable connectors. Add on cable. Take off cable. Attach holder whip cables. Split male plug permits adjusting spring tension for electrical contact. Two sizes, Sol-Con; three sizes, Mec-Con for #6 through 4/0 cable.

Tweco "Sol-Con" and "Mec-Con" plugs fit the female part of Tweco Terminal connectors for quickly connecting cables to the welding machine and to switch polarity. They are COMPANION ITEMS.

See Your Welding Supply Distributor

Tweco PRODUCTS COMPANY

TWECO PRODUCTS

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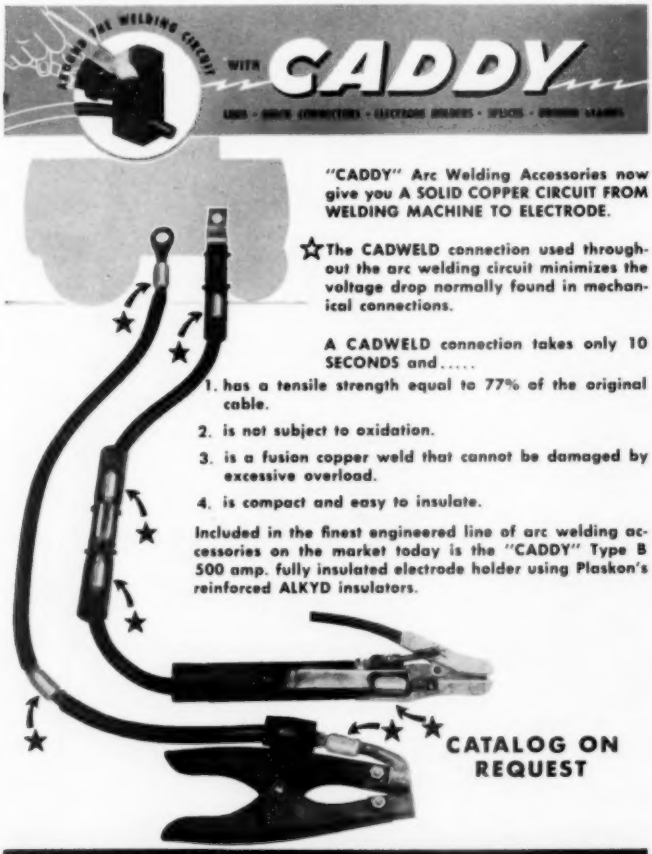
AROUND THE WELDING CIRCUIT
WITH CADDY
"CADDY" Arc Welding Accessories now give you A SOLID COPPER CIRCUIT FROM WELDING MACHINE TO ELECTRODE.
The CADWELD connection used throughout the arc welding circuit minimizes the voltage drop normally found in mechanical connections.
A CADWELD connection takes only 10 SECONDS and.....
1. has a tensile strength equal to 77% of the original cable.
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3. is a fusion copper weld that cannot be damaged by excessive overload.
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Included in the finest engineered line of arc welding accessories on the market today is the "CADDY" Type B 500 amp. fully insulated electrode holder using Plaskon's reinforced ALKYD insulators.
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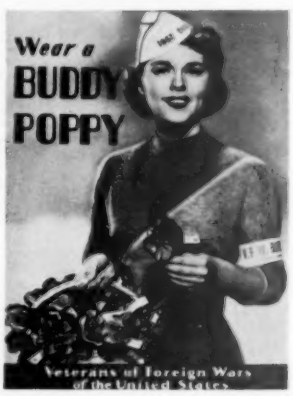


NEW PRODUCTS

Hard Facing Electrodes and Rods

A new line of hard-facing electrodes and acetylene welding rods is announced by Metal & Thermit Corp., N. Y. The new electrodes, recently added to the Murex line, include rods for extreme abrasion, medium and heavy impact, severe shock, high red hardness, and extreme heat and corrosion resistance. In addition there is a new Murex tungsten-carbide rod which provides an exceptionally slag-free deposit, allowing all residue to be readily cleaned away by wire brushing. Descriptive literature may be obtained by writing to the company at 100 E. 42nd St., New York 17, N. Y.

Low Temperature Brazing Flux for Titanium

Handy & Harman of 82 Fulton St., N. Y., N. Y. announces the development of a special brazing flux for use in the joining of titanium and zirconium, and their alloys. Silver brazing alloys readily wet the titanium which is protected by the flux.

Although titanium and zirconium form brittle compounds with most metals and alloys that may be used for brazing, the embrittlement may be minimized by rapid heating and limiting the time at brazing temperature. For this reason, low temperature brazing alloys are preferred. The lower temperature also minimizes oxygen and nitrogen contamination of the titanium. Tensile strengths of 45,000 to 50,000 psi. are obtained with butt joints in commercially pure titanium. Lap joint test specimens may break outside the joint if the lap is more than three times the thickness. Heating may be done with either oxyacetylene torch or furnace; ordinary brazing technique is used.

This new flux is being produced at the Handy & Harman laboratory from reagent grade chemicals and is available in one-half pound jars. It is called Special Handy Flux for Titanium.

Sealer

An aluminum-colored "weld-through" sealer originally used in auto manufacturing has now been made available to industry generally by the Adhesives and Coatings division of Minnesota Mining and Manufacturing Co., Detroit 2, Mich.

The sealer is applied to faying surfaces before spot welding, thus eliminating the need for a sealing operation after welding. It does not interfere with the welding operation.

The sealer is a heavy pastelike material that has "the unusual property of resisting the heat and pressure of welding without splattering or burning," the 3M company pointed out. It is soft enough to uniformly squeeze away from the bottom weld when electrode pressure is applied, without flowing away excessively.

Auto manufacturers use the material to seal the spot-welded joint between the roof and side panels, to seal along drip moldings, and to seal the joint between the rear quarter panel and the wheel housing.

The sealer shuts out air, dust and moisture, withstands paint oven temperatures up to 475° F., is not brittle at −10° F., does not support combustion, and protects metal from corrosion. It is applied with a hand calking gun or pressure extruding equipment, or can be applied in small quantities with a scraper or putty knife.

Technical data sheets and small samples are available on request.

Acetylene Compressor for Cylinder Filling Plants

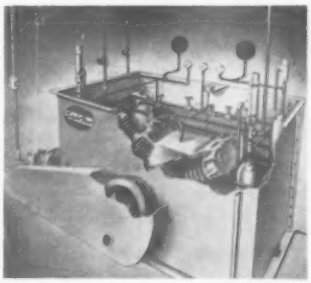
The Sight Feed Generator Co., West Alexandria, Ohio, has developed a specially designed acetylene compressor for cylinder filling plants, according to new literature the company now has ready for distribution.

The compressor unit is to be known as the Model "M-1" and will be a component part of the company's complete acetylene compressing plants. Sight Feed's medium pressure Model A-Twin Continuous Flow Generator supplies acetylene to the compressor without necessity for gas holders, which simplifies both installation and operation of acetylene filling plants.

The "M-1" is a four-cylinder, three-stage compressor submerged in water for maintaining the acetylene cool at all times during the compressing period. In conjunction with the compressor, Sight Feed has designed a fore-cooler, an inter-cooler between each stage of compression and an after-cooler to assure the lowest possible acetylene temperature in each of the three stages of compression. Integral parts of these coolers are condensation and oil traps for continuous and effective removal of impurities, moisture and oil for each cooling coil in the compressor.

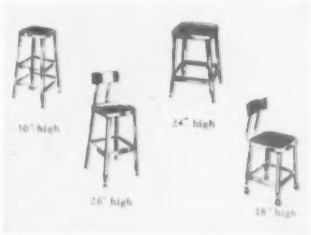
As a result of using four cylinders and more complete removal of heat and condensation from the acetylene before, during and immediately after compression, efficiency and safety of the compressor are greatly increased.

Additional features of the unit include light-weight construction and simplicity in operation.



Steel Stools

These sturdy steel stools that will stand up under abuse and yet are designed for seating comfort, are available in five heights and 80 models. They may be had with steel or pressed wood seats. Adjustable steel backs also are available.



These steel stools are manufactured by Lyon Metal Products, Inc., with general offices in Aurora, Ill., and manufacturing plants in York, Pa., and Aurora, Ill.

Some of the outstanding features of the Lyon steel stools are: large, comfortable square seats with rounded corners; all-welded, nonbreakable construction; round edge steel band legs—no rough edges to snag or tear clothing; strong channel brace, uniform distance below seat, providing comfortable foot rest; legs tapering out to insure against tipping.

Aluminum Brazing Alloy

A. E. Ulmann & Associates, Ltd., New York City, announces a new product Brazinal for brazing aluminum and its alloys, without fluxes. The properties of Brazinal are as follows: Melting point 880° F.; tensile strength 45,000 psi.; Bhn. 80.

These salient features are claimed for the Brazinal process:

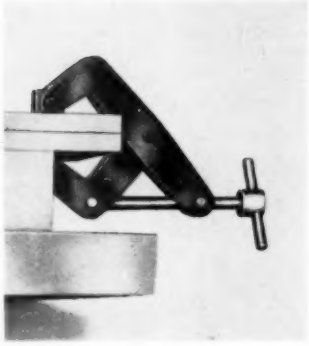
(1) Replacement of high-temperature welding with simple equipment and unskilled labor; (2) elimination of corrosive fluxes; (3) elimination of joint cleaning after brazing; (4) no galvanic corrosion

with Brazinal's carefully balanced alloy composition; (5) excellent corrosion resistance in salt spray test in acid conditions and in high humidity atmospheres; (6) minimizing of warpage which occurs in higher temperature processes; (7) elimination of preheating in many cases; (8) joining of thin sheets, thickness as low as 0.004 in. have been joined; (9) ease of application independent of shape or size; (10) speed and low cost.

Brazinal is available in triangular rod in several sizes. The rod is supplied in lengths of 12, 15 and 18 in. For additional information, write to A. E. Ullmann & Associates, Ltd., 342 Madison Ave., New York 17, N. Y.

New Clamp

A newly perfected and patented principle in clamping, has been recently introduced by the Centinela Industrial Supply Co., 11930 Inglewood Ave., Hawthorne, Calif.



The new unit, trade-named the Saxton Clamp, is case hardened and, according to its manufacturer, combines the best features and strength of a standard drop forged "C" clamp and a toolmaker's parallel clamp.

One added feature of the Saxton Clamp, it is reported, is the three different grippling faces which are built into the clamp to accommodate all types of holding jobs. A single clamp may be used for rough welding, general assembly, fast production or delicate tool and die work. The new unit is available in five different sizes—1½, 3, 6, 9 and 12 in.

Gouging and Chamfering Electrode

A new electrode designed for gouging, chamfering, cleaning and partial milling operations on any metal or alloy has been announced by Eutectic Welding Alloys Corp., Flushing, N. Y.

Important time savings are claimed by the manufacturer since the new product, "ChamferTrode," it is claimed, speeds up fabricating of armor plate and similar difficult-to-cut alloys.

The newly developed "ChamferTrode" features a heavy coating which forms a cone at the striking end of the electrode, providing a natural jet effect arc. Thus an intense, concentrated source of heat is created which readily removes unwanted metal of all types so swiftly, according to the manufacturer, that the metal, itself, remains relatively cool.

The surface of the gouged or chamfered material that has been acted upon by "ChamferTrode" is said to be free from oxidation and slag, thereby providing a clean surface for later brazing or welding operations which may be desired.

Regular d.-c. welding machines are used as the power source. The new chamfering electrode requires no auxiliary oxygen, no special gases, no air or other special equipment.

Further details, technical specifications, etc. may be obtained by writing the manufacturer: Eutectic Welding Alloys Corp., Dept. P, 172nd St. at Northern Blvd., Flushing 58, N. Y.

Hand Pyrometer

A new General Electric hand pyrometer is now available. Known as Type FH-1, it has two scale ranges for the rapid and convenient measurement of surface, liquid, gas and molten metals temperatures.

Three interchangeable tips available for the FH-1, include a surface tip, an immersion tip for liquids and molten metals, and a two-pronged contact tip. Typical applications include temperature checks of plastic molds, metals used in die casting, and preheated metals for welding. Additional information may be obtained by writing to General Electric Co., Schenectady 5, N. Y.

Insulated Electrode Holder

A fully insulated holder, the Caddy Type B 500 amp., has been placed on the market by Erico Products, Inc., Cleveland 3, Ohio. According to the manufacturer, this holder is lighter in weight, only 25 oz., more efficient and cooler operating than conventional electrode holder.

Other features are: (1) No mechanical connections; (2) the cable gripper at the rear of the steel body prevents any flexing at the weld and eliminates the need of insulating the connection; (3) the insulators are made of the New Plaskon reinforced Alkyd and (4) adjustable spring tension.

UNITED STATES
TESTING COMPANY, INC.

INSPECTION and TESTING of
Welding and Weldments
QUALIFICATION of
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WELDING CONNECTORS

Saxe Welding Connection Units position and secure structural parts to be welded.

Clip K3A permits an adjustable connection.

These widely used units eliminate all hole punching, and, with welding, produce the most economical, safe, and quickly erected structural frame.

Write for 1951 edition, Structural Welding Practice Manual.

J. H. WILLIAMS & CO.
Buffalo 7, N. Y.

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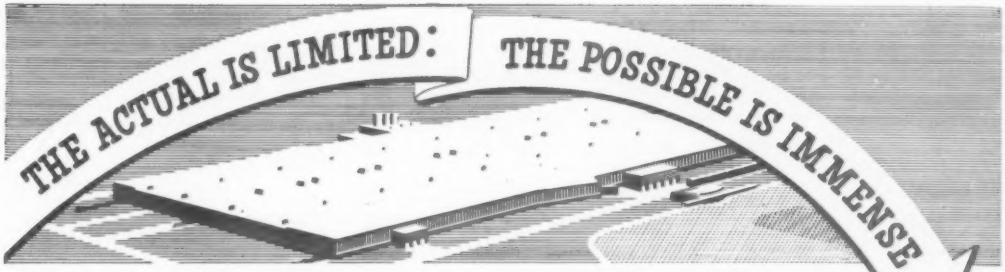

NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT

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WELDED DESIGN IMPROVES APPEARANCE

. . . while cutting costs 50%

BY converting to welded steel, this progressive manufacturer has achieved a more modern, better selling appearance for his products. At the same time he has cut costs 50% on some components.

Pleasing appearance in a product generally indicates efficient use of materials in its design. With welded steel, cumbersome and often costly dead weight, inherent with gray iron, is essentially eliminated. Wall thicknesses in steel are of exact design size. In addition, steel can be shaped at low cost with simple shop equipment.

While attaining stronger, more rigid products, in addition to improved appearance, savings in materials alone often run as high as 85%. Your Lincoln representative can show you how to apply the cost-saving benefits of steel to your products. Call or write.

Incentive Management—A thought-provoking approach to developing greater teamwork between employee and employer. Written by James F. Lincoln. Price only $1.00 postpaid in the U. S. A.; $1.50 elsewhere.

Fig. 3. Steel-Designed Blower *built by The Blairdmat Company, Oklahoma City, Oklahoma. Eliminates milling and drilling operations . . . is easier to clean and paint.*

PROPER DESIGN IN WELDED STEEL ALWAYS IMPROVES PRODUCT AND LOWERS COST

Fig. 1. Original Construction. *Required 41% more metal than present welded steel design. Heavier weight with gray iron added to handling costs in shop, in shipping and final installation.*

Fig. 2. Present Weldesign in Steel. *Saves 50% on cost. Has better appearance . . . greater selling appeal. Is stronger . . . more rigid.*

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SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Difficult Welding Problems

Baltimore, Md.—Alan G. Hogaboom, AWS, Bethlehem Steel Co., Shipbuilding Division, Quincy, Mass., gave a very good talk at the February 15th meeting of the *Maryland* Section, on some of the problems encountered in welding the hulls and machinery components of various types of ships. Mr. Hogaboom pointed out the main considerations in shipbuilding are quality, speed, efficiency and the welding of special materials. Warpage and cracking are two of the main problems encountered. His talk was illustrated with slides showing practical examples of problems and their solution. Mr. Hogaboom spoke of the difficulty encountered with the warpage of the hull and deck plates and the methods developed for straightening them and reducing the initial distortion. A great deal of interest and discussion was aroused on the best methods to be employed when welding cracks in cast iron.

As an after-dinner feature two motion pictures were shown through the courtesy of the Baltimore and Ohio Railroad and the Association of American Railroads. These were "Roaring Rails" and "The Railroad and Defense."

Weld Metal

Bethlehem, Pa.—R. T. Breymeier, AWS, Union Carbide and Carbon Research Laboratories, Niagara Falls, N. Y., was an interesting speaker at the February 4th meeting of the *Lehigh Valley* Section held at the Hotel Bethlehem. Mr. Breymeier showed colored high-speed motion pictures of the action of the weld metal in the welding arc gap for various materials, welding currents and inert gases. He also showed and explained numerous slides of graphs which depicted the physical characteristics of the weld metal under varying welding conditions.

Welding Machines

Bethlehem, Pa.—The annual joint meeting of the *Lehigh Valley* Section and the local chapter of the ASCE on March 3rd started with dinner at the Hotel Bethlehem with approximately 40 members present. The coffee speaker was L. Hauser, AWS, of the Westinghouse Electric Corp., Pittsburgh, who spoke on the comparative safety of a.-c. and d.-c. welding machines.

At 8:00 P.M. J. O. Bickel, Principal Associate of Parsons, Brinckenhoff, Hall and MacDonald, spoke and showed slides concerning the Elizabeth River Tunnel. The tunnel is 3350 ft. long with a 22-ft. wide roadway in a $^{5}/_{16}$-in. thick, 35-ft. diameter shell with $^{1}/_{2}$-in. permanent concrete forms outside the shell. There were seven sections approximately 300 ft. long prefabricated at Bethlehem Steel, Sparrows Point, Md., the ends sealed and then towed to the construction site.

A trench was dredged in the river bottom, the tubes floated over the trench, accurately located and sunk by pouring concrete in the permanent forms welded on the outside of the shells.

This $17,000,000 project of bridge and tunnel between Norfolk and Portsmouth, Va., is scheduled for completion in June 1952.

George Murphy, resident engineer for the same engineering firm, showed and commented on color films taken during the construction.

Welding Stainless Steels

Boston, Mass.—The January 4th meeting of the *Boston* Section had the largest attendance of the season with 113 at dinner and 148 present at the technical session both of which were held in the Campus Room, Graduate House at M.I.T. After dinner 22 students from the night class in welding at Wentworth Institute in Boston came to hear the technical speaker, who was G. E. Linnert, AWS, Research Welding Metallurgist, Armco Steel Corp., Baltimore. Mr. Linnert gave a fine talk on the problems encountered in welding stainless steels, and the meeting was very instructive. Mr. Linnert is a co-author of the second edition of the book published by the AMERICAN WELDING SOCIETY entitled "Welding Metallurgy."

The coffee speaker, Irwin Noyes Gould, gave a very interesting account of the management of political campaigns. Mr. Gould is a Sales Promotional Adviser on Product Sales and Market Development, and he has also been employed in "Promoting the Politician" which was the subject of his talk.

Welded Steel Structures

Boston, Mass.—A joint meeting with the Structural Section of the Boston Society of Civil Engineers was held on February 11th by the *Boston* Section in the Campus Room of the Graduate House, M.I.T. A cocktail and social hour preceded a very fine dinner.

Ernest Adams, District Vice-President of District No. 1 made his official visit to the Boston Section and was the first after-dinner speaker. Frank A. Cundair, Chairman of the Structural Section of the Boston Society of Civil Engineers, also gave a short talk, followed by George King, the coffee speaker, who told about the good work the Union Rescue Mission, of which he is Superintendent, is doing in rehabilitating men in a slum section of Boston, called "Skid Row." Mr. King, who was originally a foreman at Hood Rubber Co., Watertown, Mass., has long done social welfare work, and in 1950 he joined the Union Rescue Mission as a full time worker. He had a very interesting story to tell and after the meeting a fine donation was contributed by the members present to help him carry on his good work.

The technical speaker, Van Rensselaer P. Saxe, Structural Designer of Baltimore, gave a fine account of his contribution to the advancement of welding in the fabrication and erection of steel structures.

Weldability

Buffalo, N. Y.—R. E. Somers, AWS, of the Bethlehem Laboratories of Bethlehem Steel Co., Bethlehem, Pa., addressed the *Niagara Frontier* Section February 28th meeting of a group of 106, on the subject "Weldability of Steel." The talk was given at the Supervisory Force Social Club of the Bethlehem Steel Co. and dealt with research and methods interesting to the executive, the engineer and the production departments. Prior to the dinner held at the same place as the meeting, a plant visit was made at the Bethlehem Steel Co.'s new strip mill which is located in Lackawanna (near Buffalo), where ingots are rolled out to 54-in. widths and plate rolling is conducted both on hot and cold sheets. The hot sheets travel at a speed of 25 to 30 miles and cold sheets at 50 to 60 miles per hour. These speeds were "eye openers" to many of the visitors who had not theretofore realized the high speed of strip mill operation. The visit started at 2:30 P.M. and lasted until 5:30 P.M.

Get-Together

Chicago, Ill.—The Program Committee and the Board of Directors of the *Chicago* Section decided to have one good fellowship evening with no technical speaker and the December meeting, held on the 14th, was selected.

The speaker, Edward McFaul, lived up to all expectations, but the Chicago weatherman did not. One of the nastiest and stormiest evenings of the winter took place. With 120 reservations, 99 brave souls defied the tempest to enjoy one of the most pleasant evenings the Chicago Section has had in a long time.

Cocktails were served from 5:45 P.M., with dinner at 7:00 P.M. Following dinner, Edward McFaul gave one of his humorous talks on "So You Think You Are Slipping," which was thoroughly enjoyed by all.

Following the speaker the bar was again opened and the balance of the evening was spent in solving all of the worldly and local problems.

A good time was had by all as evidenced by the fact that the lights had to be blinked many times to remind a very large percentage of those attending that they had to go home as the club wished to lock up.

Actually and seriously this meeting had one very beneficial effect. It enabled 99 people to get better acquainted with 98 other people than the usual type of meeting affords.

The consensus of opinion was that this type of meeting is desirable on a limited scale and plans were made to have the May meeting of the same general type only substituting a technical speaker as the speaker of the evening.

The May meeting will be held on May 18th.

Design of Welded Piping

Chicago, Ill.—The largest attendance of this season heard a most interesting and informative talk on "Design of Welded Piping" given by Frank S. G. Williams of the Taylor Forge & Pipe Works, at the January 18th meeting of the *Chicago* Section held in the Auditorium of the Peoples Gas Light & Coke Co. One hundred and seven were present at the meeting; 53 had dinner at Burke's Grill and Restaurant.

A film "Fur and Feathers in Alaska and Salt Water Wonderland" was also very well received.

Annual Ladies Night

Cleveland, Ohio.—The annual Ladies Night Meeting of the *Cleveland* Section was held on February 13th in the Ball Room of the Allerton Hotel with an attendance of 170. A fashion show was put on by Franklin Simon & Co., Shaker Square. Each lady was presented with a corsage and a small bottle of perfume. A drawing was made for 10 door prizes and the main door prize—a ladies Gruen watch. A buffet luncheon was served at 10:00 P.M. and the meeting adjourned at 11:00 P.M. This was a lovely party and a huge success.

Structural Steel Welding

Dallas, Tex.—An attendance of over fifty were benefited by the information given by LaMotte Grover, AWS, of the Air Reduction Sales Co., New York, on the subject, "Structural Steel Welding" at the January 23rd meeting of the *Dallas* Section held in the Lone Star Gas Co. Auditorium.

Refreshments were served at the conclusion of the technical session.

Nondestructive Testing

Dallas, Tex.—A joint meeting of the *Dallas* Section with the ASME, ASM, ASTE and ASTM was held on February 13th in the Lone Star Gas Co. Auditorium with an attendance of 142. Carl Betz, AWS, Executive Vice-President, Magnaflux Corp., Chicago, gave a semitechnical illustrated talk on "Some Aspects of Nondestructive Testing."

Design of Weldments

Dayton, Ohio.—Earl Obringer, AWS, design engineer for The Lincoln Electric Co., described the basic outline and thinking behind their new course entitled "Weldesign" at the February 12th meeting of the *Dayton* Section held in the Victor Emmanuel Library Auditorium of the University of Dayton. Mr. Obringer's remarks were primarily concerned with the welding of mild carbon steel. He stressed the importance of confidence in a process and gave several examples of the large margin of safety the designer has in welded joints. Also the fact that, in mild steel welding, operator technique is not too important from the standpoint of ultimate strength.

Designs for strength and designs for rigidity were described from the basis of reducing the amount of welding to a minimum.

Following the talk on "Weldesign" Mr. Obringer described the Lincoln Electric Incentive and Bonus System. A lively question-and-answer period followed this portion of the talk.

Because of the general interest in the subject, the AIEE and ASME were invited to join in this meeting.

The meeting adjourned to the University cafeteria for doughnuts and coffee.

Present-Day Welding

Denver, Colo.—A full and entertaining meeting was held by the *Colorado* Section on January 14th at the Oxford Hotel, this city. Coffee speaker was F. L. Waugh of the Colorado State Game & Fish Dept. Mr. Waugh gave a short talk and showed a movie, entitled "Sunrise Serenade," through the courtesy of the State Game & Fish Dept. Both were good.

Julius Heuschkel, AWS, of the Westinghouse Electric Corp., gave an extemporaneous talk on present-day welding as applied to industry and welding in American engineering education. Mr. Heuschkel's talk was technical and covered methods, applications and processes.

Ladies Night

Denver, Colo.—Ladies Night was the feature of the February meeting of the *Colorado* Section held on the 12th at the Oxford Hotel, with an attendance of 55.

Herman Geller, AWS, of the Stearns Roger Mfg. Co., this city, was the coffee speaker. His subject, "What Welding Means to the Home Owner and Housewife," was good.

Speaker at the meeting was Dr. David Bayless of Boys, Inc. Dr. Bayless gave an extemporaneous talk on "Togetherliness" which was also good.

A 16-mm. film, "A Stone's Throw from Heaven," was shown through the courtesy of the Sheridan Brewing Co. of Sheridan, Wyo.

This was the first Ladies Night for the Colorado Section and it proved very successful. The Section will no doubt plan to have an annual Ladies Night hereafter.

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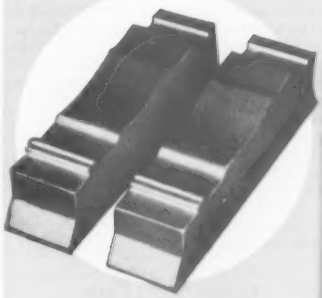

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Conference on Electric Welding

Detroit, Mich.—The Third Conference on Electric Welding sponsored by the AIEE in cooperation with the *Detroit* Section and the Industrial Electrical Engineers' Society of Detroit will be held on Apr. 16, 17 and 18, 1952, at the Engineering Society of Detroit, 100 Farnsworth, Small Auditorium.

The subject "AIEE Third National Welding Conference" will feature technical papers providing the newest developments in arc and resistance welding, exchange of information with equipment manufacturers, research and ultimate users, actual demonstrations of new machines and new techniques.

The Demonstration Sessions will be held on Thursday and Friday. On Thursday from 5:30 to 10:00 P.M., admission will be by badge only. On Friday, the same time will be open to members and guests of cooperating societies. The demonstration sessions will provide exhibit of the latest electronic controls for all types of resistance-welding machines and arc welders, and live demonstrations will be given of several types of welders using these controls.

Technical sessions covering all aspects of resistance welding and arc welding are scheduled and will be invaluable to all.

Ladies Night Party

Detroit, Mich.—On Saturday evening, May 17th, the *Detroit* Section will present its annual Ladies Night Party. The party will be held at the Latin Quarter, location of the 1951 party. The evening will consist of dinner, music, entertainment and dancing and, of course, the usual assortment of lovely door prizes, to be given to the lucky number ladies. The liquor situation will be the same as it was last year—bring your own—set-ups will be sold.

Because of an overlap of reservations last year, the policy this year will be to print 650 tickets and sell them through the mail order system. Each order will be returned with a recorded set of ticket numbers to the purchaser. This transaction will automatically reserve a table under the purchaser's name for the ticket numbers sold to him. The ticket number holders must sit at the purchaser's table and no place else. So, get your parties together early and order your tickets early (tables seat from six up). Remember—only 650 tickets; first come—first served!

Plant Visit

Ft. Wayne, Ind.—The February 15th meeting of the *Anthony Wayne* Section was in the form of a plant visit to the Marion Machine, Foundry and Supply Co., Marion, Ind.

The gathering of 63 formed into groups and the guides took them through the plate fabrication, machine shop and foundry, where they were pleased to see the many different weldments, the machining operations and foundry work. They were also set up and doing powder cutting of stainless steel which was very interesting.

The Section was greatly appreciative of this gesture and were extremely happy to have a plant in this area which is so cooperative.

Resistance Welding Aluminum

Grand Rapids, Mich.—"Welding Aluminum with Single- and Three-Phase Machines" was the subject presented by J. F. Deffenbaugh, AWS, of the Federal Machine and Welder Co., Warren, Ohio, at the February 25th meeting of the *Western Michigan* Section held at the Elks Club Cafeteria, this city. Mr. Deffenbaugh's subject was of vital interest to welding engineers and operators due to increased war work on aluminum in and around Grand Rapids.

Mr. Deffenbaugh received his education at the University of Miami and also the University of Wisconsin, and was then employed by the Ohio Public Service Co. as Distribution Engineer, from 1935 until 1945. He then became associated with the Federal Machine & Welder Co., as Chief Electrical Engineer, the position he now holds.

Mr. Deffenbaugh is Chairman of the RWMA Electrical Committee, Secretary of the National AIEE Electric Welding Society. For several years he was instructor for the Extension Division of the Case Institute of Applied Science, teaching a.-c. and d.-c. theory.

Chuck DeShane, former Detroit Lions Football Star, gave a very interesting talk on the operations of the Lions from a players standpoint. He also showed a sound film covering the high lights of the twelve 1951 games, narrated by Harry Wismer, noted football announcer. Interest was keen on this subject and may well lead to an annual football night, by bringing in a noted player or coach.

This was one of the most interesting meetings of the season, which was shown by the attendance and many questions asked.

Sixty-six members and guests registered for the dinner and were joined by fifteen more for the entertainment and technical session.

Valentine Meeting

Hartford, Conn.—Since the regular February meeting night of the *Hartford* Section fell on St. Valentine's Day, it was decided to make it a real Valentine Meeting—for the women as well as the men. This proved to be an excellent idea.

There was no technical discussion except for a brief talk by District Vice-President V. P. Adams on AWS activities. Instead, three most interesting films, all in color and sound, were shown.

They were: "United 6534" which showed what goes on behind the scenes in a modern airline, how the airplanes are dispatched, serviced, handled and controlled in the air and on the ground; "Pasadena Tournament of Roses"—the annual event in California in all its beauty and color; and "Round South America"—a beautiful film of the mild sunny climate of South America.

In addition, the Section was lucky to have the services of Major Walter C. Sage of the Hartford Times Travel Bureau, who gave a running commentary on the films which were loaned through the courtesy of the United Air Lines and the Hartford Times Travel Bureau.

Souvenirs were given to the ladies.

The meeting was held at the Rockledge Country Club, West Hartford.

Inspection Tour

Houston, Tex.—A highly successful inspection tour by the *Houston* Section of the plant of the Hughes Tool Co. took place on February 21st with an attendance of 182.

Symposium

Houston, Tex.—Tentative plans have been completed by the *Houston* Section to sponsor a "Structural Steel Design, Fabrication, Erection and Inspection Symposium" to be held in Cullen Auditorium at the University of Houston on May 15th.

The design of structural steel for welding will be presented in a paper by Barney Myers of the Robert J. Cummins Consulting Engineering firm of Houston.

The shop fabrication of structural steel for welding will be presented by Hubert Crick, AWS, of the Mosher Steel Co.

The erection of welded steel buildings will be presented by Homer Peterson of Peterson Bros., structural steel erectors of Houston.

The inspection of welded structural steel buildings will be presented by W. H. Greer, AWS, of the Southwestern Laboratories in Houston.

All of these firms have been pioneers in the welding of structural steel. The individuals of these firms are imminently qualified to discuss their respective branches of this construction field.

Invitations to the Symposium will be sent to all the colleges and universities in this area and to the Oklahoma sections. The State Highway Depts. are expected to be represented as well as the leading consulting engineering firms in the State.

The Houston Section extends an invitation through this announcement in THE WELDING JOURNAL to all members of the AWS to attend. The meeting will start at 7:30 P.M.

Annual Holiday Party

Indianapolis, Ind.—The roof of the Severin Hotel was taken over for the Annual Holiday Party given for members of the *Indiana* Section, their ladies, guests and children, on December 28th.

Following an excellent dinner, Master of Ceremonies Wally Nehrling and magician Duke Stearns (both local talent) provided a very lively and entertaining program. Liberal door prizes were awarded and gifts distributed among the children. Program Committee consisted of Chairman Paul Grubbs, Jim Neff, Doug Lowe and Ott Wilhelm.

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Welding Equipment

Indianapolis, Ind.—A joint presentation by J. F. Salatin and O. D. Etchison of Delco-Remy Div., G.M.C., Anderson, Ind., and members of the local AWS section, on "Maintenance of High-Speed Welding Equipment" was made at the January 25th meeting of the *Indiana* Section held at The Athenaeum. Welding experience over a two-year period and methods insuring minimum downtime were covered.

A 16-mm. film, "Pigs to Product," was shown after the meeting.

Plant Tour

Kansas City, Mo.—A plant tour through the Buick, Oldsmobile, Pontiac Assembly Division of General Motors, Kansas City, Kan., including the automotive manufacture from the body shop to the final assembly, was held on February 21st by the *Kansas City* Section.

Rex Dyer of the B-O-P Assembly Div. arranged the tour which lasted approximately two hours and was open to members and sponsor members only.

Welding in Shipyards

Long Beach, Calif.—The regular monthly meeting of the *Long Beach* Section was held on February 15th at Millers Cafe. Ron H. Davis, AWS, Welding Engineer, Long Beach Naval Shipyard, gave an excellent talk on "Welding Processes Used in Naval Shipyards." Mr. Davis is well qualified to talk on the subject as he has been associated with welding in the Navy since 1919.

The speaker traced the progress of welding since shortly after the first World War up to the present time, and explained the solution of many welding problems.

The Executive Committee met on the following Tuesday, the 19th, and the accompanying picture was taken at that time.

The members of the Executive Committee shown in the picture are: Rear row—J. J. Carl, Fred Silk, Ben Laughlin, Paul Anderson, Frank Pope. Middle row—Tommy Lewis, Howard Epperheimer, O. B. Bowers. Front row—Carlos Redding, Paul Treosti, Mel Teeter and Ray Davenport.

Low-Cost Welded Fabrication

Los Angeles, Calif.—Franklin R. Drahos, AWS, metallurgist for Byron Jackson Co., this city, was the speaker at the February 21st meeting of the *Los Angeles* Section held at Scully's Cafe, with an attendance of 65 at dinner and 80 at the meeting. His talk on "Flexibility of Design for Low-Cost Welded Fabrication" covered the welding of high-tensile, heat-resistant and corrosion-resistant alloys as they are used in the fabrication of centrifugal pumps. Byron Jackson uses low-alloy steels, stainless steels, Hastelloy, Monel, Inconel and other materials in various combinations for their weldments.

Mr. Drahos stressed the importance of striving to obtain proper chemical composition in the weld metal, commensurate with the properties of the parts being welded. With the assistance of slides he described how unique designs are made possible by welded fabrication. He pointed out the importance of controls on filler metal, joint design, welding procedure and operator qualification.

The group was shown the various stages in the fabrication of six large centrifugal pumps for the Grand Coulee Project. These mammoth pumps have a 14-ft. suction and a 12-ft. discharge. They pump 700,000 gal. per minute and require 65,000-hp. motors to drive them. The volute case consists of four central castings welded together and surrounded by welded sections of truncated cones.

Mr. Drahos has been a member of the AWS for about five years. He serves on the executive committee of the Los Angeles Section. He is also a member of the American Society for Metals. His engineering training includes both the University of Iowa and the University of Southern California.

Warpage and Distortion

Louisville, Ky.—The *Louisville* Section had the pleasure of hearing H. S. Sayre, AWS, Welding Engineer, U. S. Naval Engineering Experiment Station, Annapolis, Md., give a talk on "Warpage and Distortion" at the February 26th meeting.

Mr. Sayre handled this difficult subject in a manner that made it possible for all to readily understand this complex problem.

The Section is continuing its buffet dinner which has proved very popular.

The meeting closed with a motion picture "On The Track" which showed the development of railroads through the ages.

Meeting Dates

Milwaukee, Wis.—The April meeting of the *Milwaukee* Section will be held on the 25th.

The Annual Party will be held on May 24th.

Arc Welding Electrodes

Milwaukee, Wis.—"Characteristics of Arc Welding Electrodes" was the subject presented by Eller B. Lutes, AWS, Director of Production, Arcrods Corp., Sparrows Point, Md., at the regular monthly dinner meeting of the *Milwaukee* Section held on February 22nd at the Ambassador Hotel. This is a difficult type of subject to present in general discussion and was well done by Mr. Lutes. Supplemented with slides of actual welding applications he covered the field on the basis of AWS classification, operating characteristics, geometry of deposits, mechanical properties and their effects on particular applications. His wide experience in the welding and electrode field resulted in a fine question-and-answer session at the conclusion of his lecture.

The after-dinner program featured Edwin Olson of Bloedels Jewelers, Milwaukee. Mr. Olson is a member of the American Gem Society and is a Certified Gemologist. His excellent talk and sparkling table full of diamonds, rare gems, cut stones and minerals was most enthusiastically received. So many questions were asked of Mr. Olson that it was quite late before the technical speaker could lecture.

Welding Marine Turbines

New York, N. Y.—N. L. Mochel, AWS, Westinghouse Electric Corp., Steam Turbine Div., Philadelphia, Pa., gave an excellent presentation on "Welding in Marine Turbines" at the regular monthly dinner meeting of the *New York* Section held at Schwartz's Restaurant on February 19th.

Mr. Mochel is a native of Pittsburgh, and during his entire career he has been connected with Westinghouse, first with the old Westinghouse Machine Co. and later with the Westinghouse Electric and Manufacturing Co. At present he holds the position of Manager of the Metallurgical Engineering Dept. and Consulting Engineer.

For many years, Mr. Mochel's activities have been connected with the Steam Division, and thus he is extremely capable to present the above subject.

This meeting was also a joint meeting with the Society of Naval Architects and Marine Engineers. Mr. Mochel's topic was not only of interest to the members of the Naval Architects, but it also was of importance to welding engineers.

An attendance of 115 were present at dinner and 135 at the technical session, which was in charge of A. M. Setapen, AWS, Handy & Harman, New York.

Weekly Lectures

New York, N. Y.—Six weekly lectures on "How to Weld the Engineering Metals" given by outstanding authorities in their fields, on the highly important subject of

Members, Executive committee, Long Beach Section

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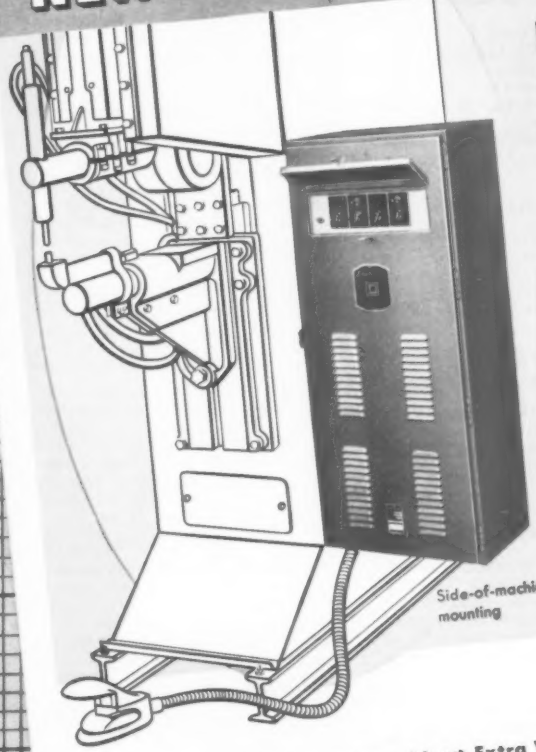
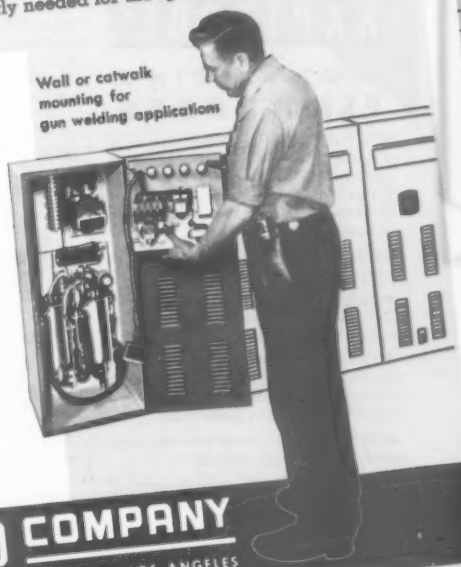


Side-of-machine mounting



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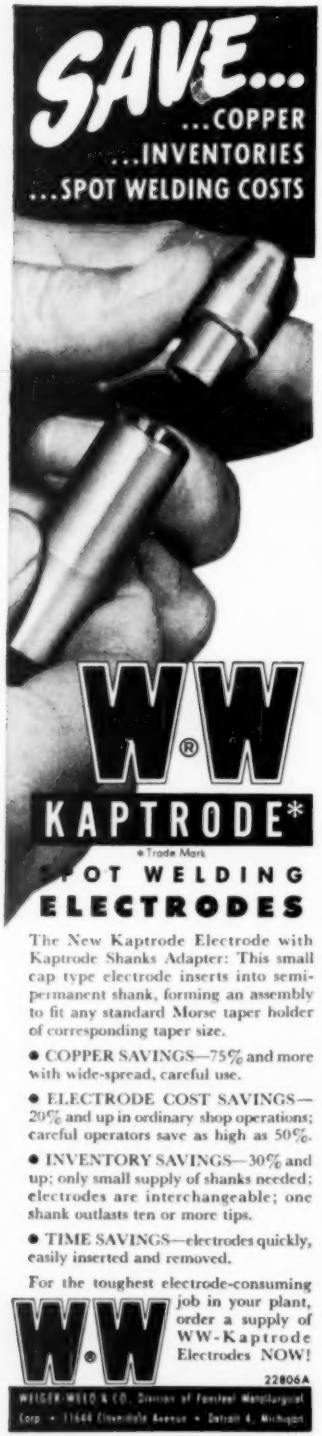
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welding the various common engineering metals and alloys, were started on Mar. 24, 1952, under the sponsorship of the *New York* Section. Each lecture will cover in a practical and detailed fashion the welding of one group of materials and will include information on: What electrodes to use; the best joint designs and preparation; Preheating and postheating requirements, and welding procedures.

A Certificate of Completion of the course will be awarded based on satisfactory attendance.

The lectures are being held on six Monday evenings in the Auditorium, 13th floor, Consolidated Edison Co., Inc., 4 Irving Place, New York City. The entire series of six lectures is $5.00 to members and $10 to nonmembers.

The last lecture will be held on April 28th.

Social

New York, N. Y.—May 9th is the date of this year's annual stag smoker put on by the *New York* Section at the Building Trades Club. A good show, fine dinner and lots of fun are promised for all.

Professional Engineers Exhibition

New York, N. Y.—All members of the *New York* Section have been invited to attend the Professional Engineers Exhibition at the Hotel New Yorker on May 1, 2 and 3.

Magnetic Particle Testing

Oklahoma City, Okla.—C. E. Betz, AWS, Executive Vice-Pres., Magnaflux Corp., Chicago, was the speaker at the February 12th meeting of the *Oklahoma City* Section held at the Hoof to Horn Restaurant and attended by 47 members and guests.

Mr. Betz gave a very interesting and enlightening talk on magnetic particle testing in industry, touching on and discussing the relative values of other nondestructive testing processes.

The bouquet of the month goes to Marion Funk, AWS, of the Halliburton Oilwell Cementing Co., Duncan, Okla., who drives over one hundred miles to attend the Oklahoma City Section meetings and seldom misses a meeting.

Low-Hydrogen Electrodes

Pascagoula, Miss.—"Low-Hydrogen Electrodes" was the subject of an excellent talk given by C. A. Young, Jr., AWS, Welding Engineer, General Electric Co., Welding Div., Macon, Ga., at the February 6th meeting of the *Pascagoula* Section. Mr. Young's address was semi-technical in nature and covered research, methods and applications and was of general interest to all.

High-Temperature Piping

Peoria, Ill.—E. R. Seabloom, AWS 2nd Vice-President, Supervisor Field Engineering, The Crane Co. of Chicago, presented a talk on the subject, "Welding of Carbon and Alloy Steels for High Temperature Service," at the February 20th meeting of the *Peoria* Section. Mr. Seabloom's talk was on the practical side of the subject and proved to be very interesting and educational. It was well illustrated by the use of slides.

The discussion period at the end of the talk was well participated in by the audience.

The meeting was held at the Sazarac Restaurant where 61 members enjoyed the dinner and meeting.

The April dinner meeting of this Section will be held on the 16th; the May meeting to be held on the 21st will be a business meeting.

Coming Events

Philadelphia, Pa.—The April 21st meeting of the *Philadelphia* Section will be a "Battle of the Sections" with the New York, New Jersey and Baltimore Sections competing for prizes.

The Annual Dinner Dance of this Section will be held on May 17th.

New Steels

Portland, Ore.—Elmer E. Gunnette, AWS, representative for the American Institute of Steel Construction, Seattle, gave a talk on "New Steels as Viewed by Welding and the Construction Industries" at the dinner meeting of the *Portland* Section held on February 26th in the Mallory Hotel, this city.

Mr. Gunnette outlined the different codes applying to steel today. This was a very instructive discussion as it brought out that one code, such as the A57, applies to the physical characteristics of steel such as tensile strength, elongation, etc., whereas the AISI and SAE codes are for the chemical characteristics of steel. The importance of carbon content not exceeding 0.3 was brought out also.

Different types of low-alloy high-tensile steel made from the AR242 specification were also mentioned with the value as to weldability.

Welding Clinic

Richmond, Va.—J. M. Tippett, Unionmelt Manager, Eastern Region of the Linde Air Products Co., gave a very good lecture with high-speed movie film showing methods of welding aluminum, etc., at the February 21st meeting of the *Richmond* Section.

The Richmond Section has secured the C.A.P. Hangar at the Byrd Airport for the "Welding Clinic" it will put on shortly. This exhibition will show the various machines and processes used in welding, and also a film will be shown. A good representation of welders, welding equipment and other process machinery is expected.

Nonferrous Metals

Rochester, N. Y.—Warren V. Waterbury, AWS, Research and Development

EUTECTIC WELDING ALLOYS CORPORATION

$2000 PRIZE COMPETITION AND PROGRAM OF AWARDS FOR CONTRIBUTIONS TO THE ART OF WELDING

OPEN TO: Engineers, Metallurgists, Researchers, Instructors, Welders, Students, and all others qualified.

FOR PAPERS ON:

Category A:	*Category B:*	
WELDING ENGINEERING & THEORY	PRACTICAL WELDING APPLICATIONS	Covering technological and research aspects, procedures and applications of the use of lower melting (lower than parent) filler metals in the non-fusion welding processes.

AWARD FUND:

Category A:		*Category B:*	
First Prize	$500.	3 First Prizes	$100. each
Second Prize	$300.	4 Second Prizes	$ 50. each
Third Prize	$200.	20 Third Prizes	$ 25. each

The Jury and Committee of Awards:
1. Dr. Robert Humphrey, Vice Chairman American Society for Metals
2. Prof. Otto H. Henry, Dept. of Metallurgy, Polytechnic Institute of Brooklyn
3. Dr. Th. I. Leston, Vice President, Eutectic Welding Alloys Corporation

RULES:

1. The program is open to all persons qualified to present basic principle, theory or the results of practical research and application in the field of non-fusion "lower melting temperature" filler metals in welding, except employees of Eutectic Welding Alloys Corporation, its advertising agencies and members of their families.

2. Participants may submit welding papers on one or more of the following subjects:

(a) Oxy-acetylene, low melting filler
(b) Oxy-fuel gas, low melting filler
(c) Brazing and bronze welding
(d) Silver alloy filler metals
(e) Soldering filler metals
(f) Hard facing and resurfacing with a low melting filler
(g) Lower melting filler metals for metallic arc, inert arc and carbon arc applications

The welding applications may be torch, furnace, induction, carbon arc, inert arc or metallic arc.

3. Papers must consist of not less than 1000 words, exclusive of drawings, specifications, tables, etc.

4. Manuscripts should be typed in English, double spaced on 8½"x11" white paper, with any tables, charts or drawings on separate sheets.

5. Papers should be confined specifically to the fields defined above and may be documented with photographs, charts, drawings, tables or test data.

6. All papers must be the original, previously unpublished work of the participant and must bear his name, address and business or professional connection.

7. Papers will be judged by the Jury and Committee of Awards on the basis of the merit of the theory or practice presented. Decisions of the judges will be final. All entries and ideas therein become the property of Eutectic Welding Alloys Corporation, and none will be returned.

8. The competition opens October 1st, 1951 and closes June 30th, 1952 midnight. All entries must be postmarked on or before that date.

9. Winners of awards will be notified by mail within approximately 60 days after the close of the competition. Complete list of winners will be sent to all participants requesting it.

Write for entry blank and helpful suggestions on the preparation of papers

Papers should be submitted to:
Prize Competition and Program of Awards,
EUTECTIC WELDING ALLOYS CORPORATION
172nd Street at Northern Boulevard, Flushing 58, New York.

629

Two "Georgia Tech" men win EUTECTIC'S 1950 competition

J. M. MARTIN (right) and C. L. Ramsey (below), both of the School of Chemical Engineering, Georgia Institute of Technology, shared First Prize in last year's competition, heading a list of seventeen award winners.

EUTECTIC WELDING ALLOYS CORP.
172nd Street and Northern Blvd., Flushing, New York

Please send me ..... entry blanks and helpful suggestions on the preparation of papers for the EUTECTIC Prize Competition and Program of Awards.

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Affiliation .....
Address ..... Zone .....
City ..... State .....

WJ-4

Dept., Revere Copper and Brass, Inc., Rome, N. Y., was the guest speaker at the February meeting of the *Rochester* Section.

Mr. Waterbury's talk consisted primarily of the different welding processes by which copper base nonferrous alloys may be satisfactorily joined by welding.

A question-and-answer period followed and many interesting discussions developed.

Prior to the meeting, dinner was served to a large group at the Rochester Turners Club, followed by a film taken on the battlefield in Korea that proved of great interest to all.

The Rochester Section thanks the management of Revere Copper and Brass, Inc., for making it possible to have Mr. Waterbury with them.

Quiz Program

Saginaw, Mich.—A Quiz Program on arc, gas and resistance welding with Godfrey Burrows, AWS, Quiz Program Moderator, was held on February 14th following a chicken dinner at the Zehnder's Hotel, Frankenmuth, Mich., by the *Saginaw Valley* Section. This excellent program lasted about eighty minutes and was of general interest to all.

The Saginaw Valley Section is participating, in an advisory capacity, with Saginaw Valley Area Engineering and Scientific Societies on the problem of the serious shortage of engineers. This activity is being encouraged by the Northeastern Michigan Section of the AIEE and the Joint Engineering Council. Discussions are being held toward the end of developing interest of high school students in engineering; assisting those schools to plan their curriculum; working with college students; on the problem of improving and upgrading graduate or trained engineers; as well as interesting engineers in civic affairs and the study of municipal projects for the benefit of the public.

Maintenance Welding

Salt Lake City, Utah.—K.M. Spicer, AWS, International Nickel Co., New York, gave an outstanding talk on "Maintenance Welding of Cast Iron and Nickel Bearing Alloys" before a joint meeting of the *Salt Lake City* Section and the local ASM chapter on February 4th at the Temple Square Hotel.

Mr. Spicer has been associated with General Electric and Babcock and Wilcox in their metal fabricating divisions. This practical experience began in 1922. He joined the Research Division of the International Nickel Co. in 1938. His work with this company has required extensive travel and a wide field of application of welding to light and heavy fabrication in the field and in the shop.

Mr. Spicer's illustrated talk was of particular interest to the group because the information was practical and useful in their local shop operations.

Al Bowcutt was general chairman and Jack Jones, technical chairman.

Field Trip

San Francisco, Calif.—After enjoying a fried chicken dinner at the San Francisco Municipal Airport on January 28th, 91 members and guests of the *San Francisco* Section were welcomed by the management of the United Air Lines Maintenance Base, and a short talk on "Welding Practices" was given by Ted Cieszko, Engineer. This was followed by a tour as guests of United Air Lines of their Maintenance Base which included Welding, Engine, Radio, Cabin Sheet Metal, Overhaul and Line Service Shops.

Pipe Line Welding

San Francisco, Calif.—Russell G. Rhoades, Welding Engineer, Bechtel Corp. San Francisco, explained, at the monthly meeting of the *San Francisco* Section held on February 25th, the principles of the double and triple ending of large diameter pipe by a 100% automatic welding process as laid out for the construction of the 30–31-in. diameter Trans-Arabia pipe line running from the Persian Gulf to the Mediterranean, a distance of 1068 miles. With some modifications this principle has been so successful that it has been used for all other similar projects throughout the world. In connection with Mr. Rhoades's talk a film, "Oil Across Arabia," was shown. This is a 16-mm. color and sound film covering the record of engineering and construction of the abovementioned pipe line. The film related the story of setting up a modern pipe welding factory in a remote area, half way around the world. It was shown through the courtesy of the Bechtel Corporation. Mr. Rhoades pioneered the welding, engineering and equipment for the field-welding plant shown in the picture "Oil Across Arabia." Mr. Rhoades discussed many of the interesting welding aspects shown in the film.

Richard Finnie, Historian, Bechtel International Corp., produced the film "Oil Across Arabia" and as a coffee talk he gave the background of this production and also related some of his experiences in the making of such a picture.

The discussion period was most enlightening as Mr. Rhoades enjoys an outstanding reputation as an authority in this field.

This was an excellent meeting.

Toughness in Welds

South Bend, Ind.—At the regular monthly dinner meeting of the *Michiana* Section held on February 21st at the Airport Restaurant, this city, Austin Hiller, AWS, Sales Engineer of the General Electric Co., Milwaukee, discussed various ramifications of toughness in welds. As toughness starts with the metallurgy of welding, Mr. Hiller described the metallurgical factors which influence ductility and strength, such as cooling rates (hardness) and soundness. He then discussed the common mild steel electrodes, E6010 and E6020, and classified them as to their various welding and weldability factors. These factors included metallurgical conditions, operating characteristics and electrical properties.

Pipe Line Welding

Springfield, Mass.—The best meeting of the year of the *Western Massachusetts* Section was held on February 7th at Blake's Restaurant, this city. J. Parish of the Northeastern Gas Transmission Co., presented a talk and movie on the subject "Gas Goes to Market." Mr. Parish talked on pipe-line welding and construction procedures. He had some samples of actual weld X-ray photographs and samples of test coupons showing the type of tests used in testing welders for proficiency before allowing them to work on pipe-line construction.

Inert Arc Welding

Toledo, Ohio—R. W. Tuthill, AWS, General Electric Co., Fitchburg, Mass., gave a semitechnical talk on the subject "Inert-Gas-Shielded Arc Welding" at the January 17th meeting of the *Toledo* Section. Mr. Tuthill's remarks were illustrated with slides.

Stainless Steel

Washington, D. C.—George E. Linnert, AWS, Armco Steel Co., Rustless Div., Baltimore, Md., spoke extemporaneously at the January 23rd meeting of the *Washington, D. C.*, Section held in the auditorium of the Potomac Electric Power Co. Mr. Linnert's excellent talk was on the subject "Designing Welded Fabrication of Stainless Steel," and was of interest to the executive, engineer, operator and production department personnel.

President Charles H. Jennings spoke briefly at the dinner which was held at O'Donnell's Restaurant.

Educational

Wichita, Kan.—"Present-Day Welding in Industry as Related to the Educational Program" was the subject of the excellent paper presented by Julius Heuschkel, AWS, Westinghouse Electric Corp., East Pittsburgh, Pa., at the January 15th dinner meeting of the *Wichita* Section. Mr. Heuschkel discussed present-day welding as applied to industry and related modern practices to the requirements of the existing engineering educational problem.

Cold-Rolled Steel Sheets

Wichita, Kan.—A joint meeting with the Wichita Section of the American Society for Metals was held on February 19th by the *Wichita* Section in the Knights of Columbus Hall. Technical speaker was William C. Northrup of the Granite City Steel Co., Granite City, Ill. Mr. Northrup spoke extemporaneously on the "Drawing Quality Cold-Rolled Steel Sheets."

Mr. Northrup is at present in the Department of Metallurgy and Inspection, Cold Strip, Hot Strip and Tin Mills of the Granite City Steel Co. He is a graduate of the University of Pittsburgh with a B.S. Degree in Metallurgy. He was formerly connected with the Weirton Steel Co. of Weirton, W. Va.

Design for Welding

Worcester, Mass.—John Mikulak, AWS, Asst. to Vice-Pres. Mfg., Worthington Pump & Mchy. Co., Harrison, N. J., gave an excellent talk on "Design for Welding" at the February 27th meeting of the *Worcester* Section held in the Tower House.

Prior to Mr. Mikulak's talk a sound, color Pan American Travelogue was shown.

Welding Metallurgy

York, Pa.—The revitalization program of the *York-Central Pa.* Section proceeds in high gear. Everyone in the Section is enthused, is working hard on programs, and Paul L. Stumpf, of the S. Morgan Smith Co., member of the Section's Board and Chairman of the Publicity Committee, is doing an excellent job of getting publicity both into the York newspapers and the S. Morgan Smith Co.'s monthly house magazine "Turbine Topics." The SOCIETY's sincere appreciation is extended to the S. Morgan Smith Co., for their assistance and excellent cooperation.

Following a very successful plant tour of the S. Morgan Smith Co.'s facilities in November, this Section held a joint meeting with the American Society for Metals, combined with a dinner, with 75 to 100 at dinner and 150 at the technical session, on February 13th at the Elmwood Grille in York. AWS Chairman Charles Pyle and ASM Chairman Dr. C. A. Sloat presided.

February 13th meeting York, Pa., Section. From left to right—Richard Lee of Alloy Rods, speaker; Dr. C. A. Sloat, Professor of Chemistry, Gettysburg College, Chairman of ASM; Charles H. Pyle, Chairman of AWS

Mr. Richard K. Lee, AWS, addressed both the SOCIETY's Sections on the "Fundamentals of Welding Metallurgy." Mr. Lee is well known in national circles of the AWS in view of his vigorous work in the national SOCIETY's technical activities. He is Vice-President in Charge of Research and Engineering for the Alloy Rods Co. of York and is a graduate of Ohio State University. Previously he was research engineer for the Steel and Tube Division of the Timken Roller Bearing Co. He is a prominent member of the Ordnance Advisory Committee on the Welding of Armor, as well as of the Arc Welding Section of the National Electrical Manufacturers Assn.

Al Roberts, ASM, American Chain Co.; Richard Lee; Dr. Sloat; Howard L. Sittler, Metallurgist of Arcrods, Baltimore; and Charles H. Pyle

In summary Mr. Lee advised that Welding Metallurgy is primarily involved with rates of heat input, high temperature of the arc and the extreme speed of the metallurgical reactions.

Electrode tip and weld crater comprise a miniature high-speed electric furnace. In less than one second metal from the arc end of the electrode and alloys from the covering are melted, superheated, mixed, deoxidized, cast into position and frozen. This can be compared to the production of steel in electric arc furnaces in which case from two to eight hours are required to melt and refine the steel.

The high localized heat input in the weld area must be taken into consideration in the development of welding procedures and the selection of electrodes. In welding mild steel practically no metallurgical problems are encountered, since the base steel is not hardenable by heat treatment. As the hardenability of the steel increases more consideration must be given to preheat, interpass temperature, postheat treatment and selection of the electrodes.

One of the greater problems in welding stainless steels is the carbide precipitation control. Arc high heat input and low thermal conductivity of stainless steel combine to allow the weld area to remain hot for an appreciable length of time. If not controlled, carbide precipitation occurs in the heat-affected zone of the base steel adjacent to the weld with resultant lack of corrosion resistance. There are three methods to control the carbide precipitation in stainless steels.

The welded structure may be fully annealed, which redissolves the carbon. Not many stainless weldments can stand being heated to 2000° F. and quenched in water to accomplish the full anneal. Usually other preventative measures are used. If sufficient columbium or titanium is added to the steel, stable carbides are formed, which prevent the carbon from migrating to the grain boundaries. Both columbium and titanium stabilized stainless steels are usually welded with columbium stabilized electrodes, since columbium can be effectively added to the weld metal from the electrodes, while titanium is oxidized and lost in the arc. Another method of controlling carbide precipitation in stainless steel welding is to remove as much carbon as practically possible from the steel. Steels and electrodes containing 0.03% maximum carbon are available. However, weldments of the 0.03% maximum carbon are not recommended for continuous corrosive service at 800° F. and higher, since there usually is a very slight amount of carbide precipitation which may be detrimental after long time exposure.

This Section is planning a National Activity Night for April and will show a film on Applied Welding Engineering provided by AWS. S. A. Greenberg, Technical Secretary of the National SOCIETY, will talk. A new plant visit is being planned for May.

Panel Discussion

Youngstown, Ohio.—On February 28th the *Mahoning Valley* Section had a Panel Discussion with the following Panel of Experts and Subjects.

C. Strutz, AWS, Oxweld Railway Service—"Torch Welding and Flame Cutting."
O. H. Kuhlke, AWS, General American Transportation—"Submerged Arc and Inert Arc Welding."
L. K. Stringham, AWS, The Lincoln Electric Co.—"Manual Arc Welding."
I. A. Oehler, AWS, American Welding & Mfg. Co.—"Resistance Welding."
R. E. Heltzel, AWS, Heltzel Steel Form & Iron Co.—Moderator.

The dinner and meeting were held in the 422 Cafe, Warren, Ohio, with 83 at dinner and 90 at the meeting.

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NEW LITERATURE

Elias E. Ries, Inventor

Elias E. Ries, Inventor, by Estelle H. Ries. This book of 369 pages deals with the life of one of the great inventors and scientists of America. It is claimed that Ries was first to invent some of the practical methods and apparatus for welding. The book represents amazing behind-the-scene stories of great inventions. It indicates the tragedies of genius when it comes into conflict with big business, absurd patent regulations, impossible economic situations and certain human pettiness.

Price $4.75. Published by the Philosophical Library, New York, N. Y.

Industrial Work Gloves

A new 8-page, fully illustrated catalog No. 52 on industrial work gloves is now available from Richmond Glove Corp., Richmond, Ind. This two-color catalog contains complete information, including description, features, packing and shipping weight on 45 types of their Bee Brand gloves. All leather, leather palm, canton flannel and Jersey gloves are featured. For additional information, contact the Richmond Glove Corp., 653 North D St., Richmond, Ind.

Surface Conditioner for Aluminum

The Nielco Laboratories have announced the availability of their Technical Data Sheet on "Alum-i-niel" 978, an acid type of surface conditioner for aluminum sheets and extruded metal prior to welding. Copies of this data sheet may be obtained by writing to Nielco Laboratories, P. O. Box 4703, Detroit 19, Mich.

Metco News

The latest issue of the *Metco News* describes, in detail, several metallizing applications that save time, money and scarce materials.

One case reported therein is that of a manufacturer of printing equipment who saved 23,000 lb. of stainless steel in one year—on one metallizing application alone. This company makes a water-roller used in the printing presses of can manufacturers for printing on tin. Since they are used with water, making them subject to corrosion, they were formerly made of stainless steel—about 40 lb. being required for each. With metallizing, however, mild steel can be used for the base and 0.080 to 0.100 in. of stainless steel sprayed on to provide the necessary protection against corrosion. They are prepared by grit blasting and finish ground. Approximately 8 lb. of stainless steel are required for each—saving about 32 lb. per roller. The company produces 60 of these parts per month. The total savings in stainless steel over a year's time exceed 11 tons of this critical material.

Another case is that of a user who reported saving a 200-lb. shaft with 19 lb. of stainless steel. This 200-lb. impeller shaft is used on a small dredge and its original 5 1/4 in.-diameter bearing journal had worn down to an average of 4 3/4 in. Nineteen pounds of stainless steel were sprayed on the worn section, 18 11/16 in.lg. for a finish coating thickness of 2/8 in. The spraying operation took only two hours. According to this same user, many such shafts are reclaimed and put back in service the same day.

Send for your copy of the *Metco News*, Vol. 5, No. 12. Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

New IAA Carbide Lime Pamphlet

"Carbide Lime, Its Value and Its Uses," a new publication prepared by the Oxy-acetylene Committee of the International Acetylene Association, has just been released. This 36-page pamphlet gives general information and technical data about carbide lime as well as details on potential uses in many fields including the chemical industry, water softening, sewage disposal, building and construction, and agriculture. Requests for copies should be addressed to H. F. Reinhard, Secretary, International Acetylene Association, 30 E. 42nd St., New York 17, N. Y.

Saga of the Abrasives Industry

The Saga of the Abrasives Industry, a 386-page book by Muriel F. Collie, has recently been published under the joint sponsorship of the Grinding Wheel Institute and The Abrasive Grain Association. This book gives a very complete picture of the establishment, development and growth of the abrasives industry in the United States, covering a period ranging from the early part of the nineteenth century to the present time. Some of the specific topics discussed are: natural abrasives, manufactured abrasives, development of grinding wheels by processes, machines and wheels, and role played by a number of companies within the industry. Additional information regarding this book may be obtained by writing to the Grinding Wheel Institute, Greendale, Massachusetts, or to the Abrasive Grain Association, 27 Elm Street, Worcester 8, Mass.

Resistance Welding at Work

A new issue of *Resistance Welding at Work* (Vol. 3, No. 5) is now available and may be obtained by writing to Scisky Bros., Inc., 4915 West 67th Street, Chicago 38, Illinois.

Steel Construction Digest

The January 1952 issue of *Steel Construction Digest* a publication of the American Institute of Steel Construction, contains several reprints and abstracts of articles dealing with welded structural framework. The titles of these articles are as follows: "All Welded Framework in New Department Store," by F. M. Burt; "Designing a Structural Frame for Economy," by E. L. Gardner; "Welded Steel Frame Lightens New Building"; "Steel Welding Cuts Noise, Cost," by W. H. Quirk; and "Field House for Champions," by J. D. Griffiths. Copies of these publications may be obtained by writing to the American Institute of Steel Construction, 101 Park Avenue, New York 17, N. Y.

Bulletins on Arc-Welding Accessories

Three new two-color bulletins on arc-welding accessories have been announced as available from the General Electric Co., Schenectady 5, N. Y.

The three illustrated bulletins describe recommended protective clothing (GEC-867), helmets and glass (GEC-865), brushes, carriers, chipping hammers, paint and weld-spatter compounds and weld gages (GEC-866). In addition to illustrating and describing the equipment, the bulletins list specifications, type and catalog numbers for each item.

Corrosion Testing

The 1951 ASTM Edgar Marburg Lecture—"Corrosion Testing"—by Francis L. LaQue, The International Nickel Co., Inc., has just been published in the form of a 96-page illustrated booklet.

This lecture comprises a survey of corrosion-testing programs and methods of corrosion testing, many of which have been sponsored by the American Society for Testing Materials. Mr. LaQue discusses the distinction that must be made between the corrodibility of a material and the protective value of its corrosion products and how these are influenced by both the composition of the material and the incidental conditions of its exposure.

Some of the topics touched on in the book are as follows: atmospheric corrosion studies, relations between rust color and corrosion, effects of alloying elements on the resistance of steels and irons to atmospheric corrosion, comparison of atmospheres, and galvanic corrosion. Also discussed are a variety of tests such as: acid, accelerated, atmospheric galvanic, salt spray, laboratory total immersion and

alternate immersion, boiling nitric acid, plant corrosion, paints, etc.; tests in waters, corrosion tests of insect screens, long-time tests of different steels and irons, and effects of position in test.

Copies of this 96-page booklet, heavy paper cover, can be procured from the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., at $1.50 each.

Bronze Welding

An 8-page reprint entitled, "Jobs You Can Do with Bronze Electrodes," written by F. E. Garriott, Manager of the Weldrod Department of Ampco Metal, Inc., is now available through Ampco Metal, Inc., Milwaukee, Wis.

Completely illustrated, this booklet describes the welding techniques and correct choice of bronze electrodes to be used in welding water heaters, turbine runners, cast-iron gear housings, galvanized iron exhaust stacks, bearings, dies, etc.

For your free copy, write Ampco Metal, Inc., 1745 S. 38th St., Milwaukee, Wis.

Brochure on Welding and Cutting Equipment

A 16-page, illustrated brochure describing the welding torches and cutting attachments manufactured by the National Welding Equipment Co., has recently been released by this company. Copies of this brochure may be obtained by writing to National Welding Equipment Co., 218 Fremont St., San Francisco 5, Calif.

Illustrated Folder on Brazing and Soldering

Two aluminum solders designed for joining copper to aluminum or other metals and ten rods and electrodes for work on copper and copper-bearing alloys with torch, soldering iron and arc, are featured in an illustrated folder, 6 pp., $3^1/_4 \times 6^1/_4$ in., which has just been released by All-State Welding Alloys Co., Inc., 273 Ferris Ave., White Plains, N. Y. This booklet is titled "How to Use and Apply All-State Alloys and Fluxes for Welding, Brazing and Soldering Copper and Copper-Bearing Alloys."

Contained in the folder are complete instructions for use, techniques of application and description of the properties of the alloys. Copies of this folder may be obtained from All-State distributors throughout the country or on request to the company at White Plains.

Maintenance Manual on Stud Welding

Maintaining Your Stud Welder is the title of the new Maintenance Manual being offered to industry by KSM Products, Inc. The handbook is a companion piece to KSM's Operating Manual. It represents the first time, according to this company,

an ACCO product
for Stainless Steel WELDING
AC-DC Electrodes
GAS Welding Rods
made by
PAGE
BURNING...
stable even at lower heats
SLAG...
clean, easily removed
COATING...
resists cracking down to very short stubs
SELECTION...
complete line for welding every type of stainless
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that a manual devoted exclusively to the maintenance of stud welding equipment has ever been published by a manufacturer. Designed for convenient reference by those charged with maintenance of stud-welding apparatus, the 12-page handbook contains 8 drawings and charts and 12 photographs. Accompanying text helps to clearly explain the various aspects of maintenance against a background of specific components and problems. A copy of the Manual can be obtained by writing to: Stud Welding Division, KSM Products, Inc., Merchantville, N. J.

Employment Service Bulletin

Positions Vacant

V-266. Welding Engineer. Large eastern metal-producing company has excellent opening for development and technical service work in welding. State age, education and experience.

Welding Engineer. Must be capable of planning, conducting and reporting research projects in the field of welding. Engineering graduate preferred, with three to five years experience in welding research or manufacturing. Send complete résumé and photograph to Employment Dept., International Harvester Co., Manufacturing Research, 5225 S. Western Blvd., Chicago 9, Ill.

V-268. Welding Engineer. Supervisory Engineer required by large ship repair company. Capable of introducing and controlling electric and acetylene welding methods. Experience in modern stress relieving, technical inspection and with some knowledge of metallurgy. Send complete information, together with technical and practical experience.

V-269. Excellent connection available for an experienced person of executive caliber, preferably with both engineering and business training, with a New York City welding and engineering contracting organization having more than 30 years successful background on large welding contract work of every description. Applicants should have proved experience in estimating and have inherent business management ability. Connection warrants a moderate dollar investment in the business with the opportunity for eventually assuming general management and part ownership. All replies treated with utmost confidence.

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Write TODAY for FREE Literature on SEACO! Nearest Distributor Upon Request.

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SOLE PRODUCERS
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Newark 5, N. J.

V-270. District Manager Wanted by leading manufacturer of alloy arc welding electrodes, to supervise Mid-Western territory. Primary duties: working with established distributors, establishing new distribution. Broad experience with various types of electrodes a must. Attractive financial proposition. Our employees know of this advertisement.

V-271. Sales Engineers Wanted. Various locations. Work with distributors selling hardfacing welding rod. Practical or formal training in welding field desired. Growing division of large company with excellent opportunities.

Services Available

A-626. Metallurgist, 25 years old; B.S. Metallurgical Engineering. Presently employed in research. Desires change to obtain position offering diversified experience. Would prefer the nonferrous field; main interest, applied research. Present salary $4500 year. Location is arbitrary.

A-627. Resistance Welding Engineer. Married, 3 children, age 38. Twelve years' experience on spot, seam, flash and projection welding. Employed the past seven years by resistance welding manufacturer in Experimental Welding Laboratory. Will relocate for right opportunity.

would you like to know more about this important question . . .

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Your oxygen regulator tames a cylinder pressure which may exceed 2200 p. s. i.; it must do so consistently, reliably and safely.

Just how does so sensitive an instrument, so sturdy a regulator, work — what is pressure anyway — wherein lies the difference between a pressure gauge and a tubular flowmeter — when would you select a single and when a two-stage reduction regulator — and wherein lies their difference?

On what basis do you select a regulator to meet specific requirements of low or very high delivery pressures, or minute or very vast volume of flow?

If you have asked yourself these and similar questions about pressure, about the measuring of flow, about all of the many problems your regulator must solve for you, write for this new, FREE National regulator booklet today.

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516

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NEWS OF THE INDUSTRY

Nationwide Laboratory Inspection Announced

Magnaflux Corporation announces that it has increased the national coverage of its Commercial Inspection Laboratories, from five to eleven locations. Folders are now available to briefly cover the two phases of this available inspection: laboratory inspection of parts, from one to 1,000,000, and field inspection for large objects anywhere. This inspection service is in addition to the regular manufacture and outright sale of inspection equipment by Magnaflux Corp.

Inspection laboratories are located in Chicago, Ill.; New York, N. Y.; Hartford, Conn.; Cleveland, Ohio; Detroit, Mich.; Wichita, Kan.; Dallas, Tex.; Houston, Tex.; Odessa, Tex.; Los Angeles, Calif. and Oakland Calif. Full addresses and information are shown in the Laboratory and Field Inspection folders, respectively. This inspection by Magnaflux personnel includes consultation on how best to solve problems of causes of the defects encountered, and how to establish acceptance standards. For further information and for copies of the folders, write to Magnaflux Corp., 5900 Northwest Highway, Chicago 31, Ill.

Denise Darcel Named "Miss Welder of 1952"

Denise Darcel, MGM motion picture, stage and television star, was officially named "Miss Welder of 1952" by the National Eutectic Welders' Clubs at a luncheon in the Roosevelt Hotel, New York, on February 15th.

Miss Darcel was selected as "the girl we would like most to weld with" by the graduate body of professional welders representing nation-wide industry and the armed services who attend the Eutectic Welding Institute. Her selection was based on her "outstanding qualities of beauty, physical charm, poise, determination, endurance, meticulousness, emotional stability, ready wit and unselfishness."

R. D. Wasserman, President of the Eutectic Welding Institute and the company bearing the same name, presented a scroll to Miss Darcel, expressing the hope that her photograph would inspire women throughout the nation to join the ranks of the labor force so vitally needed for America's defense effort. The luncheon was held for the purpose of announcing and demonstrating to the press a new Eutectic product, ChamferTrode, a cutting or gouging metal-removing electrode.

Welding of Steel Castings

The Tempil°Corporation of New York has announced that it is prepared to supply complimentary copies of "Recommended Practice for the Welding of Steel Castings," a 40-page booklet published by the Steel Founders' Society of America, to engineers and technicians who request it on their business letterhead. All requests should be addressed to Tempil° Corp., 11 W. 25th St., New York 11, N. Y.

1950 Acetylene, Oxygen and Calcium Carbide Production

Early in January the Industry Division of the Bureau of the Census, U.S. Department of Commerce, issued a compilation of statistics on "Inorganic Chemicals and Gases, 1950." The following figures are abstracted from the report. (Quantity units are millions of cubic feet for the gases and short tons for carbide.)

The figures on acetylene "exclude information from railroad shops, shipyards, welders and small establishments using portable generators." In 1947 data on shipments of carbide were not separately stated, but lumped into "other calcium compounds."

The 1950 statistics are based on reports furnished to the Census Bureau on Form MA-19E, "Annual Report on Shipments and Production, Consumption, and Stocks: 1950." Figures for 1947 were compiled from the 1947 Census of Manufacturers report. The production figures represent the primary manufacture of the various products in the United States, including quantities produced for further processing in the same plant, for intra-company transfer, and for sale to other companies. The data exclude information for plants either owned or operated by the Federal Government, or operated solely for its account, except for Tennessee Valley Authority plants, which are included.

Marquette Opens New Warehouse

Marquette Manufacturing Co., Inc. of Minneapolis, manufacturers of arc and gas welding equipment and automotive service equipment, has announced the opening of a new warehouse at 48-14 36th St., Long Island City 1, N. Y.

R. W. Massey, field engineer, and F. H Eckman, eastern district manager, will be in charge of this facility.

A. O. Smith Corp. Expands

Welding equipment manufacturing of A. O. Smith Corp. has moved into this 27,000-square foot Milwaukee building from overcrowded quarters at the Company's main operations at Milwaukee Works. Besides providing needed space for assembly lines for A. O. Smith's 12 basic welder models, the building also houses experimental shops and some sales offices. Space vacated at Milwaukee Works is being utilized for expanded welding electrode production, which has been at peak capacity for the past year.

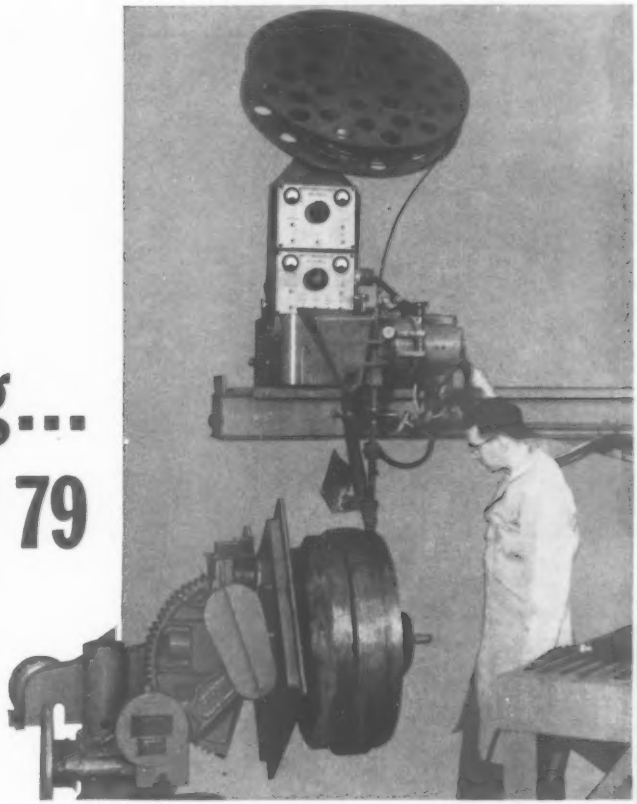
Ampco Distributor

Ampco Metal, Inc., Milwaukee, Wisc., has appointed Kirk-Wicklund and Co., Kansas City, Missouri, as a franchised distributor of Ampco Weldrod products for the northern and eastern counties of Kansas.

They will handle the complete line of Weldrod products including Ampco-Trode and Phos-Trode electrodes and Ampco-Trode bare wire and filler rods many of which they have in warehouse stock.

		Total shipments and interplant transfers		*Production*	
	Year	*Quantity*	*Value (f.o.b. plant)*	*Total Quantity*	*Consumed in same establishment, cu.ft.*
Acetylene	1950	4,327	$50,584,000	5,409	...
	1947	3,002	38,581,000	3,007	...
Oxygen (high purity)	1950	17,637	$54,676,000	17,848	235
	1947	13,878	41,522,000	14,429	585
Calcium Carbide	1950	400,958	$31,181,000	671,492	...
	1947	...	...	607,113	...

Announcing... Amsco AW 79



for AUTOMATIC HARDFACING

AMSCO AW 79 will meet your every requirement for better control of wear where abrasion and high impact are important factors—plus giving you all the advantages of automatic welding. It can be used for reclaiming parts worn to uselessness or for increasing productivity of new parts.

The result of extensive research and field testing, AMSCO AW 79 is especially suitable for rebuilding and hardfacing tractor rollers and idlers. Back-up rolls, steel wheels, sheeting rolls, dredge pins, as well as dozens of other applications, can be successfully hardfaced with AW 79. It can be used on any conventional automatic submerged arc welding equipment now being used.

AW 79, the first in a series of rods by AMSCO for automatic hardfacing, is an alloy steel electrode fabricated by encasing particles of alloy metals in a continuous steel tube. Deposits are of martensitic alloy steel with chromium and molybdenum as the principal alloying agents. It is available in coils weighing approximately 100 lbs., each with an inside coil diameter of 22½", and is stocked in wire diameters of 5/32" and 3/16". Packed in cardboard containers with an anti-rust agent, other coil diameters and sizes are available on request. Write today for complete information.

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• in uniformity
• in operator training
• in dependability
• in quality
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Pk-h — Practical know-how
Se — Service
Tr — Training
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Ask for a free copy of 32-page Buyers Guide to the complete line of ALL-STATE Alloys and Fluxes.

ALL-STATE
WELDING ALLOYS CO., INC.
White Plains, N. Y.

Foreign Organizations to Participate in Centennial of Engineering

First indication of the world-wide scope of the Centennial of Engineering to be celebrated in Chicago this summer was given today in an announcement by its president, Lenox R. Lohr, that the leading scientific societies of seven foreign nations have pledged active participation during the past week. These are in addition to the 49 American scientific and engineering bodies already announced.

In each case the foreign organizations have agreed to send sizable delegations of their best known figures to this country for the 10-day convocation, the specially created public exhibit of world engineering progress in the past 100 years, and the big spectacular stage presentation to be included in the Centennial program.

One of the largest foreign delegations will be that of the Royal Society of Industrial Engineers of Belgium which will send 11 delegates. Other bodies to be represented include the Japanese Society of Civil Engineers, the Institution of Civil Engineers of Great Britain, the Institution of Mechanical Engineers of Great Britain, the World Power Conference which has its headquarters in London with branches in France and India, the College of Civil Engineers of Mexico, the Engineering Institute of Canada, and the Association of Professional Engineers of the Province of Ontario.

Lohr also stated that other prominent engineering bodies in Norway and France are definitely pledged to participate although they have not yet indicated the exact make-up of their delegations.

European engineering societies, as well as those of Latin and Central America, will have leading parts in the ceremonies planned for the International Day program, scheduled to open the convocation meeting on September 3rd.

International Welding Congress Proceedings

The reports in English of the proceedings of the International Welding Congress held in London and Oxford in July 1951, are contained in the June, August and October 1951 issues of the *Transaction of the Institute of Welding*. The distribution of the various portions of the report between these three issues is as follows:

OPEN SESSIONS

1. The Welding of Bridges and Structures

Professor Ir. W. Soete—"Possibilities of the Pre-Stressing of Metallic Constructions," October 1951, pp. 161–168.

A. B. Kinzel, D. Swan, H. Biers and H. R. Pufahl—"Powder Processes, a New Industrial Tool," October 1951, pp. 154–160.

2. The Welding of the Wrought Light Alloys

J. Faguet—"Recent Advances in the Technique of Electric Spot Welding of Aluminum Alloys in the French Aircraft Industry," August 1951, pp. 110–120.

W. V. Binstead and E. G. West—"British Experience in the Argon Arc Welding of Aluminum," August 1951, pp. 121–139.

J. Herenguel and M. Hollard—"Recent French Studies on the Weldability of Aluminum Magnesium Alloys," August 1951, pp. 140–144.

Discussion on the three papers—October 1951, pp. 169–172

3. Recent Developments in Welding in Great Britain

J. M. Robertson—"Welding in Relation to Gas Turbines for Use on Land," June 1951, pp. 68–73.

W. S. Atkins & E. M. Lewis—"Developments of Design and Fabrication in recent British Structures" June 1951, pp. 74–84.

H. E. Lardge—"Welding on Gas Turbine Engines for Aircraft" June 1951, pp. 85–91.

Discussion of the three papers—October 1951, pp. 173–176

4. Reports of Chairman of Commissions

October 1951, pp. 177–182 and 159

General Report

August 1951, pp. 104–106

Copies of the three issues are obtainable for £ post free by writing to G. Parsloe, Secretary, The Institute of Welding, 2 Buckingham Palace Gardens, Buckingham Palace Road, London SW1.

Centennial to Encourage Engineering Training

Stating that America's colleges and technical schools are preparing only about half as many trained engineers as the country needs, Lenox R. Lohr announced today that one of the main objectives of the Centennial of Engineering, to be celebrated in Chicago later this year, will be to inspire more young men and women to take up engineering as a career.

Welding Show and Clinic

Williams and Co., Inc. will hold a Welding Show and Clinic in the new 10,000 sq. ft. addition to their Pittsburgh warehouse on April 2–4, 1952.

Twenty to twenty-five of the larger suppliers of welding materials handled by Williams and Co. will have booths at this welding clinic with welding specialists in attendance to discuss welding problems. These companies include The International Nickel Co., Inc., Tempil® Corp., Welding Equipment & Supply Co., Merrill Bros., Aladdin Rod and Mfg. Co., Chicago Tool & Engineering Co., Linde Air Products Co., Lukens Steel Co., Handy & Harman, Aluminum Company of America, American Brass Co., Arcos Corp., American Manganese Steel Division, Erico Products, Inc., Jackson Products, Inc., Mir-O-Col Alloy Co., Inc., Solar Aircraft Co., Thompson & Co., Westinghouse Electric Corp., AMERICAN WELDING SOCIETY, and Industry and Welding.

A welding forum will be scheduled at regular intervals where open discussions of various problems in welding can be discussed and also films illustrating the use of welding and brazing in industry will be shown at scheduled intervals. These meetings will continue daily Wednesday and Thursday from 1 to 9 P.M. and Friday from 1 to 6 P.M.

Radiography checks—

then double checks

LANDING GEAR STRUTS lead a life of punishment. Though light, they must be strong. Their joints must be sound. Radiography is the method used to prove them sound.

A maker of amphibian aircraft goes even further. Though treated and sealed, strut members can develop internal corrosion and become weakened. Radiography alone can provide the required nondestructive examination of these internal surfaces. So it has become routine to x-ray these struts as part of the periodic inspection of the planes.

This is but one example of how radiography is proving a boon to the welding process. It is helping to open new fields for the use of welding—especially in the fabrication of highly stressed products and assemblies.

Look into the ways Radiography can aid your business. Your x-ray dealer will be glad to give you full information and assistance.

EASTMAN KODAK COMPANY
X-ray Division, Rochester 4, N. Y.

Radiography—

another important function of photography

Kodak
TRADE-MARK

abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,582,963—Seam-Welding Apparatus—John F. Cachat, Cleveland, Ohio, assignor to The Ohio Crankshaft Company, Cleveland, Ohio, a corporation of Ohio.

This apparatus is for continuously welding opposed edges of a generally C-shaped metal strip and it includes high frequency, induction-heating inductor for inducing high-frequency currents to flow in the edges of the strip and raise them to welding temperature, and members are provided for pressing such heated edges into welding engagement. A feature of the patent resides in a piston and cylinder arrangement for moving the members into pressure engagement and the strip and hydraulic pressure means are connected to the piston-cylinder arrangement to exert a substantially uniform pressure against the strip. This hydraulic system functions in accordance with a formula to maintain the desired pressure.

2,583,002—Flame Cutting Machine—Glenway Maxon, Jr., Milwaukee, Wis.

Maxon's machine is for flame cutting gears and includes a rotatable spindle for carrying the blank, a cutting torch and means mounting the torch to reciprocate toward and from the spindle to cut through a blank thereon. Special means are provided for cutting teeth of different sizes in the gear blank and for rotating the blank an arcuate distance equal to the circular pitch of the gear to be cut with each reciprocation of the carriage.

2,583,045—Method of Thermochemically Cutting Ferrous Metal—Harold R. Fisher, Metuchen, N. J., assignor to Air Reduction Company, Incorporated, New York, N. Y., a corporation of New York.

This method is particularly directed to the cutting of steel containing chromium and it includes projecting a stream of cutting oxygen against the steel and introducing into the oxygen stream a powdered flux consisting essentially of at least one material selected from the group of sodium sulphite, sodium sulphate, sodium bisulphate and sodium thiosulfate.

2,583,507—Polyphase Alternating Current Fusion Welding With Control of Interphase Voltage, and with Combined Alternating Current and Direct Current Welding Potentials—Otis R. Carpenter and Frank W. Armstrong, Jr., Barberton, and Reidar P. C. Rasmusen, Akron, Ohio, assignors to The Babcock & Wilcox Company, Rockleigh, N. J., a corporation of New Jersey.

Electric welding apparatus is covered by this patent and it includes a plurality of relatively movable electrodes, a relatively fixed electrode and means connecting the electrodes in a polyphase welding circuit. First circuit characteristic responsive adjustment means are associated with the movable electrodes and control the arc lengths therebetween, and second circuit characteristics responsive adjustment means are associated with the movable and fixed electrodes and operate conjointly with the first adjustment means to control the arc lengths between the movable electrodes and the fixed electrode.

2,583,575—Welding Machine—Ernest Katz, Haifa, Palestine; now by judicial change of name Ernest Henry Casson.

This patent relates to a spot welding machine for uniting superpositioned flexible sheet metal pieces that have an intermediate perforated work piece therebetween. Annular holding means press the work pieces together and annular electrodes apply heat to and deform the sheet metal pieces at the location of the perforation in the intermediate work piece. Spot welding electrodes are provided to apply welding heat to the deformed areas of said metal pieces. Guide means are also operatively connected to the apparatus and move in predetermined sequence to the remainder of the apparatus.

2,583,665—Gas Blanketed Arc Welding—Frank J. Pilia, West Orange, N. J., assignor, by mesne assignments, to Union Carbide and Carbon Corporation, corporation of New York.

In this welding method, a gas confining nozzle is advanced to bring its rim into contact with the metal to surround a spot thereon and simultaneously a non-depositing electrode is directed inside of and concentric with the nozzle toward the center of the said spot. The electrode is positioned with its tip spaced from the spot and from the nozzle rim, and pressure is exerted on the nozzle to cause a ring of pressure contact between the nozzle rim and the work to surround the spot and steady the nozzle. A layer of non-oxidizing gas is maintained above the nozzle rim and extending over the spot, while an arc is struck between the electrode tip and the spot through the layer of non-oxidizing gas. This arc is maintained until the spot is heated to fusion temperature and molten portions of the work coalesce. The ring of pressure contact and the electrode are maintained stationary for the duration of the arc.

2,583,868—Resistance Welded Dome Nut—Anthony Thaddeus A. Mocium, Manhattan Beach, Calif., assignor to North American Aviation, Inc.

This patent covers a method for attaching a dome nut to a metallic pressure vessel and comprises press fitting the dome nut into a hole in the vessel, and passing a welding current through the press fit to fuse the metal around the circumference of the nut.

2,584,072—Backup Device for Welding, Brazing or Soldering Operation—Herbert E. White, Cleveland Heights, Ohio.

White's patent is on a device for soldering or similar operations on thin sheet stock and it includes a horseshoe-shaped permanent magnet having two spaced apart legs terminating substantially in a plane. A back-up plate is provided, and connector means secure the back-up plate to the magnet means with the back-up plate located between the legs. Spring means are included in the connector means to bias the back-up plate normally to a location beyond the ends of the legs.

2,584,491—Means for Spot Welding—Ted Nelson, San Leandro, Calif., assignor to Gregory Industries, Inc., a corporation of Michigan.

Nelson's patent is on a fusible electrode including a stud and welding flux at one end of the stud. An annular groove is provided in the stud dividing the electrode into a fusible head and a chuck receiving body.

2,585,127—Composition for Cleaning Aluminum and Aluminum Alloy Surfaces Preparatory to Spot Welding—Emmette B. Holman, Pasadena, and Justine L. Mathis, Ranchita, Calif., assignors to Turco Products, Inc., Los Angeles, Calif., a corporation of California.

This new cleaning composition consists of an aqueous acidic solution of about 5% to 50% by volume of a non-halogen inorganic acid. About 0.25% to 20% by weight of another substance is present and it dissociates in the solution into a pyrophosphate radical and another ion.

2,585,266—Pressure Welding Machine—Russell T. Murray, El Cerrito,

Three HAYSTELLITE inserts protect each of the blades on these two pug mill screws from the abrasive action of linoleum ingredients.

A handful of Tungsten Carbide Inserts gave this mixer an Extra Year of Life

Masticator blades in this pug mill-type mixer for processing linoleum failed in less than three months, because of severe abrasive wear. Much of this wear was eliminated by tack-welding three HAYSTELLITE cast tungsten carbide inserts to each of the blades on the screw. The inserts were applied easily without removing the blades from the mill.

After it was equipped with hard-faced blades, the mixer remained in service for nine months without blade maintenance, and it was still good for six months more. This five-to-one life more than offsets the cost of the inserts.

For more information on HAYSTELLITE tungsten carbide products and seven other HAYNES hard-facing materials, write for the 40-page booklet, "HAYNES Alloys—Hard-Facing Manual." The booklet contains data on how to select the right rod and how to make the deposit by either the oxy-acetylene or metallic-arc welding process.

HAYNES TRADE-MARK *alloys*

Haynes Stellite Company
A Division of
Union Carbide and Carbon Corporation
UCC
General Offices and Works, Kokomo, Indiana
Sales Offices
Chicago — Cleveland — Detroit — Houston
Los Angeles — New York — San Francisco — Tulsa

"Haynes" and "Haystellite" are trade-marks of Union Carbide and Carbon Corporation.

and Florindo Viti, San Francisco, Calif., assignors to Grove Regulator Company, Oakland, California, a corporation of California.

A machine for butt pressure welding operations is provided and includes hydraulic means and relatively movable members providing a closed chamber between the hydraulic means and the abutted metal members to be welded. Said chamber is adapted to receive gas under pressure. Liquid supply means are provided for said hydraulic means and pneumatically controlled means regulate such liquid supply means and are at least partially controlled by relative movements between the said members.

2,585,772—Method and Circuit for Pulsation Welding—Andrew D. Hasley, Basking Ridge, and Frank H. Hibbard, Mountain Lakes, N. J., assignors to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York.

Resistance spot welding of small parts is covered in this patent. It discloses utilizing the drop in resistance in the weld to prevent burning of the weld. A plurality of welding pulses are sent through parts maintained under continuous welding pressure, each welding pulse singly being of insufficient energy to make the weld and being of microsecond duration.

LIST OF NEW MEMBERS

Effective February 1, 1952

ANTHONY WAYNE
Makley, Clarence F. (B)

BIRMINGHAM
Bates, John W. (C)

BOSTON
Evans, Frank H. (C)

BRIDGEPORT
Bauer, William A., Jr. (B)
Simpson, Frederick G. (C)

CHATTANOOGA
Davis, Bert (B)

CHICAGO
Phares, Earl K. (B)
Stross, Francis H. (B)
Weger, Delmar C. (C)

CLEVELAND
Laughman, Earl S. (B)
Lee, Ralph (C)
Milicia, Anthony (C)
Walasko, Theodore L. (B)

COLUMBUS
Mitchell, David R. (D)
Morgan, Richard L. (D)
Traxler, Fredrick E. (C)

DALLAS
Buckingham, Edward L. (B)

DAYTON
Shockey, Howard J. (C)

DETROIT
Anderson, Walter B. (C)
Broniak, Leonard (C)
Grappin, Lloyd (C)
House, John I. (B)
Jiggens, Warren, Sr. (C)
Jiggens, Warren E., Jr. (C)
Manning, Matthew J. (B)
Phillips, Hugh L. (B)
Ruese, Daniel J. (B)
Shy, Clem L. D. (B)
Stoynoff, Richard (C)

HARTFORD
Conley, Leo F. (C)
Grieco, William T. (B)
Roberts, William A. (C)
Yankowski, Joseph (B)

HOUSTON
Billeaud, F. R. (C)
Maden, Ross E. (B)
Randall, Milton Dudley (C)
Rice, Leonard N. (B)

INDIANA
Luley, Richard A. (B)

LONG BEACH
Carse, David B., Jr. (C)

LOS ANGELES
Asbury, Homer L. (C)
Bladholm, E. F. (C)
Concannon, Charles W. (B)
Corse, Thomas S. (C)
Dahl, Marion H. (B)
Hay, Robert Alan (B)
Jones, W. H. (C)
Kensrue, Milo M. (B)
Smith, William H. (B)

MAHONING VALLEY
Butler, W. J. (C)
Wood, Thomas J. (B)

MARYLAND
Kennedy, William E. (C)

MILWAUKEE
Deiter, Ed (C)
Prodoehl, Clemens F. (C)

NASHVILLE
Daniels, Gordon E. (B)

NEW JERSEY
Anderson, Stanley Augustus, Jr. (C)
Mazak, John, Jr. (B)
Munson, George (B)

NEW YORK
Granniss, Edward R. (B)
Horowitz, William H. (B)
Marden, Jonathan (B)
Maser, Roland H. (B)
Mintern, Michael J. (C)
Tanner, Jack Lawrence (B)

NIAGARA FRONTIER
Quenzler, W. C. (C)
Thompson, Daniel P. (B)
Van Riper, John (B)

NORTHERN NEW YORK
Taylor, James (B)

PEORIA
Barlow, James B. (C)

PHILADELPHIA
Boyer, Thomas H., Sr. (C)
Franks, Ernest H. (B)
Kelly, Edward P. (C)
Kelly, James M. (B)
Pogacar, Charles F. (B)

PITTSBURGH
Lawton, C. L. (C)
Miller, Mike A. (B)

PUGET SOUND
Renn, Alan C. (B)
Wilcox, Robert L. (C)
Woodside, James H. (B)

RICHMOND
Stinson, Z. T. (C)

SAGINAW VALLEY
Bishop, Felix J. (B)
Daoust, Edward (B)
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Welded Reinforcement of Openings in Structural Steel Members

A determination of strain energy distribution and true stresses in the plastic range in plates with centrally located openings

by D. Vasarhelyi and R. A. Hechtman

I. INTRODUCTION

THE research reported herein is a part of the investigation of welded reinforcement of openings in structural steel members. A previous paper[1] described the tests of $^1/_4$-in. plates with and without welded reinforcement. The purpose of the tests covered by this report was to determine the unit strain energy and the true stress distribution in the plastic range of the material in a flat plate with a centrally located opening, which was square with rounded corners. Two such plates made from plain-carbon semi-killed structural steel were tested in tension, one at room temperature and the other at a temperature of $-20°$ F., the first of which failed with a completely shear fracture and the other with a fracture almost entirely cleavage.

The octahedral theory[2] was used to determine the unit strain energy distribution, while the true stresses were computed by a method developed in the course of the investigation. Both types of analyses utilized the experimental data of the tests as the basis of the computations.

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II. UNIT STRAIN ENERGY DISTRIBUTION IN THE PLASTIC RANGE OF THE MATERIAL DETERMINED BY THE OCTAHEDRAL THEORY

The octahedral theory, whose application to the problem of plastic distortion was suggested by A. Nadai,[2] utilizes the convenient relations between the octahedral shear stress and the octahedral shear strain in expressing the stress-strain condition at a point in a multiaxial stress field and from these quantities develops the unit energy absorption at the point.

Only a brief discussion of the method will be presented here. By the equilibrium of forces and the geometry of the strains, the equations for the octahedral shear stress, the octahedral shear strain, and the unit strain energy at a point in the stressed body become as follows:

$$U = \frac{3}{2}\int \tau \, d\gamma \tag{1}$$

For the condition of uniaxial stress,

$$\tau = \frac{\sqrt{2}}{3}\,\sigma_x \tag{2}$$

$$\gamma = \sqrt{2}\,\epsilon_x \tag{3}$$

For the condition of triaxial stress,

$$\tau = \frac{1}{3}\sqrt{(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2} \tag{4}$$

$$\gamma = \sqrt{\frac{8}{3}}\sqrt{\epsilon_x^2 + \epsilon_x\epsilon_y + \epsilon_y^2} \tag{5}$$

The symbols in these equations are defined in Section VIII of this report. Because of the large deformations occurring in the plastic range, it is necessary to use true stresses and natural strains at all times in the application of these equations.

These equations are based on the following necessary assumptions:

1. Isotropic behavior of the material occurs throughout the plastic range.

2. The directions of the principal stresses and of the principal-strains coincide at all times.

3. The entire strain energy is distortional energy, that is, the volume of the deformed body remains constant.

Experimentally, the procedure consists of two steps; first, the determination of the energy absorption per unit volume in a uniaxially stressed specimen such as a tensile or compression specimen for various values of the octahedral shear strain; and, second, the determination of the values of the octahedral shear strain at different points in the specimen with the complex stress field and the assignment at each of these points of a value of energy absorption found in the uniaxially stressed specimen for an equal value of the octahedral shear strain.

In the application of the octahedral theory to the present problem, two simplifying assumptions were made which brought a small degree of approximation into the test results, principally in the vicinity of the notch:

1. The plate with an opening was considered as a plane stress problem, in that the stress in the direction of the thickness of the plate was neglected.

2. The principal stresses always lay in the x- and y-directions of the coordinate system.

III. EXPERIMENTAL DETERMINATION OF TRUE STRESSES BY USE OF TENSILE TEST DATA

An experimental procedure has been devised for applying the true stress-strain relation in the simple tension or compression test to plane stress problems in plasticity. A typical true stress-strain curve for a simple tension test of a structural steel is shown in Fig. 1. The tangent to the curve at a point having the ordinates $\bar{\sigma}$ and $\bar{\epsilon}$ is denoted the tangent modulus or E_T, and the intercept of this tangent on the natural strain axis is called β.

The following two equations may be written to express the strains at a point in a plane stress problem:

$$\epsilon_x + \beta_x = \frac{\sigma_x}{E_{Tx}} - \frac{\mu_{yx}\sigma_y}{E_{Ty}} \qquad (6)$$

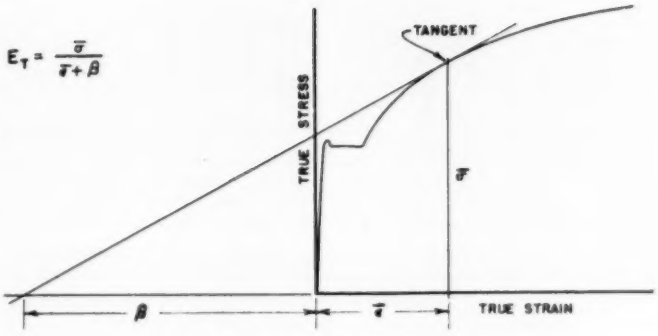

Fig. 1 Graphical definition of E_T and β

$$\epsilon_y + \beta_y = \frac{\sigma_y}{E_{Ty}} - \frac{\mu_{xy}\sigma_x}{E_{Tx}} \qquad (7)$$

Definitions of the symbols used in these equations may be found in Section VIII. These equations assume that the tangent modulus E_T remains constant in the region of the stress-strain curve in which the computation is being made—an assumption that does not introduce much approximation in this particular problem, since the true stress-strain curve for structural steel approaches linearity in the region between the end of the lower yield point range and the point where necking begins.

The simultaneous solution and rearrangement of Eqs. 6 and 7 gives these expressions for σ_x and σ_y:

$$\sigma_x = \frac{1}{1 - \mu_{xy}\mu_{yx}}\left([E_{Tx}(\epsilon_x + \beta_x)] + \mu_{yx}\frac{E_{Tx}}{E_{Ty}}[E_{Ty}(\epsilon_y + \beta_y)]\right) \qquad (8)$$

$$\sigma_y = \frac{1}{1 - \mu_{xy}\mu_{yx}}\left([E_{Ty}(\epsilon_y + \beta_y)] + \mu_{xy}\frac{E_{Ty}}{E_{Tx}}[E_{Tx}(\epsilon_x + \beta_x)]\right) \qquad (9)$$

The quantities in the two brackets in each equation are simply the true stresses in the uniaxial true stress-strain curve, $\bar{\sigma}_x$ and $\bar{\sigma}_y$, which correspond to the apparent natural strain values, ϵ_x and ϵ_y, measured on the specimen. Equations 8 and 9 may then be rewritten as,

$$\sigma_x = \frac{1}{1 - \mu_{xy}\mu_{yx}}\left(\bar{\sigma}_x + \mu_{yx}\frac{E_{Tx}}{E_{Ty}}\bar{\sigma}_y\right) \qquad (10)$$

$$\sigma_y = \frac{1}{1 - \mu_{xy}\mu_{yx}}\left(\bar{\sigma}_y + \mu_{xy}\frac{E_{Ty}}{E_{Tx}}\bar{\sigma}_x\right) \qquad (11)$$

These last two equations may be applied directly to the computation of true stresses in a plane stress problem in plasticity. The apparent natural strains, ϵ_x and ϵ_y, are measured on the specimen. From the true stress-strain curves for the material tested in the x- and y-directions, the values of the true stress, $\bar{\sigma}_x$ and $\bar{\sigma}_y$, corresponding to these apparent natural strains are found. When these true stress values are sub-

stituted in Equations 10 and 11, the true stresses, σ_x and σ_y, in the specimen are determined.

While the derivation presented here is not rigorously exact in a theoretical sense, it involves little approximation when applied to common structural metals.

IV. TEST SPECIMENS AND TEST METHODS

All the specimens described in this report were made from the same heat of plain-carbon semi-killed steel which met ASTM Designation A7–49T and was used in the as-rolled condition. The chemical analysis of this steel, which was called Steel U, was as follows:

C	0.23
Mn	0.50
P	0.053
S	0.051
Si	0.07

The tensile properties in the direction of rolling as found from the average results of two tests of ASTM standard flat tensile specimens from each plate were as follows:

Plate No.	*Upper yield point, psi.*	*Ultimate strength, psi.*	*Elongation in 8 in., %*	*Reduction of area, %*
26	36,900	61,800	34.9	61.6
4	34,900	60,200	32.2	60.7

The transition temperature was determined by the Navy tear test for Plate No. 4 and found to be 40° F. The plate specimens, Nos. 38 and 38A, which were tested at the lower temperatures were cut from this plate, while Spec. No. 37 came from Plate No. 26.

A sketch of the tensile specimen used to obtain the relation between the unit energy absorption under uniaxial stress and the octahedral shear strain is shown in Fig. 2. The blanks for these specimens were sawed from the parent plate and machined to width. Duplicate specimens cut in directions both parallel and transverse to the rolling direction were tested. The calibration tensile specimens and the corresponding plate with an opening were cut from the same plate and tested at the same temperature.

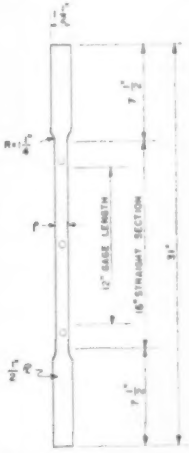

Fig. 2 Sketch of tensile calibration test specimen

Three identical large plates with a central opening of the type shown in Fig. 3 were tested: the first, Spec. No. 37, at room temperature; the second, Spec. No. 38A, at a temperature of 0° F. to determine the load-average elongation curve and the kind of fracture to be expected at this temperature; and the third, Spec. No. 38, at a temperature of −20° F. The unit energy distribution over the surface of the plate and the true stresses on cross sections of the plate were investigated in the first and third tests.

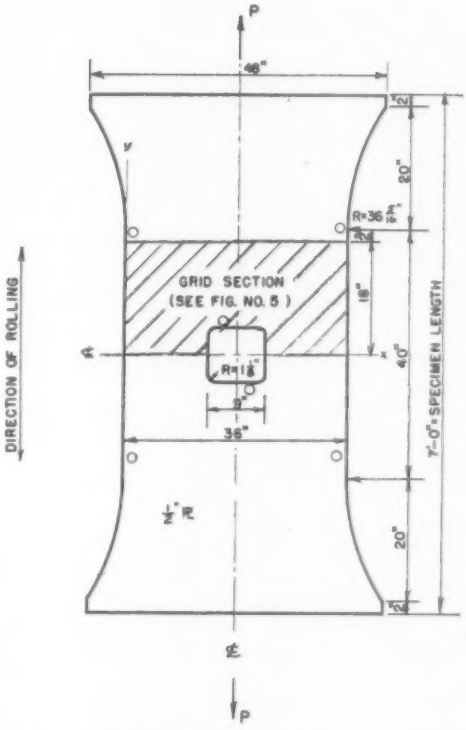

Fig. 3 Plate with square opening with rounded corners

These large plates were fabricated and tested with pinned end connections in tension in a 2,400,000-lb. testing machine in the manner described in the previous paper.[1] For the low-temperature tests, the specimen and the pulling heads were enclosed in a well-insulated chamber, through which cold air was circulated.

Spec. No. 38A was gaged with slide-wire resistance gages on 18- and 36-in. gage lengths and SR-4 gages. A rectangular grid system of horizontal and vertical slide-wire resistance gages sensitive to a movement of about 0.002 in. was mounted on both faces of Specs. Nos. 37 and 38. These gages consisted of high-resistance wire strung through contact points mounted on the surface of the specimen. The movement of the contact points resulted in a change in the gage length and, therefore, a change in resistance of the gage. In the region adjacent to the opening, the spacing of the grid lines was 1 in., while in sections remote from the opening larger spacings were used.

The test was run continuously and, because of the

many readings required, extended over about fifteen hours.

V. CALIBRATION TENSILE TESTS AND PILOT TEST

The following procedure was used in obtaining the relation between the unit energy absorption in the calibration tensile specimen of the type shown in Fig. 2 and the octahedral shear strain:

1. During the course of the test, readings of the elongations in 12 in. and the instantaneous width and thickness were taken up to the maximum load on the specimen.

2. These data were reduced to the form of true stress-strain curves for the plates in the direction of rolling as shown in Fig. 4.

3. From the data in Step 2, the octahedral shear stress-octahedral shear strain curve was derived by the application of Equations 2 and 3.

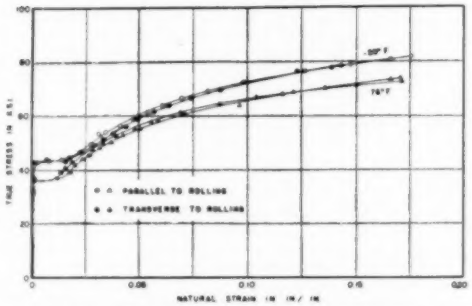

Fig. 4 Calibration test true stress-strain curves

4. The relation in Fig. 5 between the unit energy absorption and the octahedral shear strain was computed from the data in Step 3 by the use of Equation 1.

The values of Poisson's ratio in the directions parallel and transverse to the rolling direction were required for the computation of the true stresses. The following values of Poisson's ratio were found experimentally:

Plate No.	*Testing temperature ° F.*	*—Poisson's ratio in direction— Parallel to rolling*	*Transverse to rolling*	*Use values for spec. No.*
26	76	0.48	0.46	37
4	−20	0.51	0.46	38

The slopes of the tangents to the true stress-strain curve in the plastic range were called the tangent modulus, E_T. The values found in these calibration tests are plotted in Fig. 6.

While the transition temperature of the $^1/_2$-in. plate material had been determined by the Navy tear test, it was unknown for the large plates with a square opening with rounded corners. Therefore, a pilot test was made on Spec. No. 38A at a temperature of 0° F. and resulted in a fracture which was 87% cleavage. A shear fracture started at the diagonally opposite

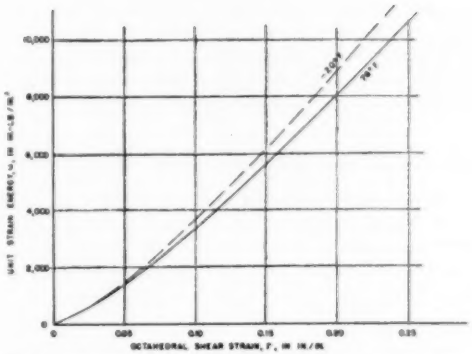

Fig. 5 Relation of unit strain energy absorption and octahedral shear strain for calibration test specimen

corner of the opening and, after progressing a short distance, changed to a cleavage fracture. As a result of this test, it was decided that the testing temperature for Spec. No. 38 should be −20° F.

The load-average elongation curve for this specimen is shown in Fig. 7.

VI. TESTS OF TWO LARGE PLATES WITH SQUARE OPENING WITH ROUNDED CORNERS

1. *Tests and Type of Fracture*

Spec. No. 37 was tested at a temperature of 76° F. and Spec. No. 38 at a −20°. The fracture of the former was entirely shear, while for the latter it was

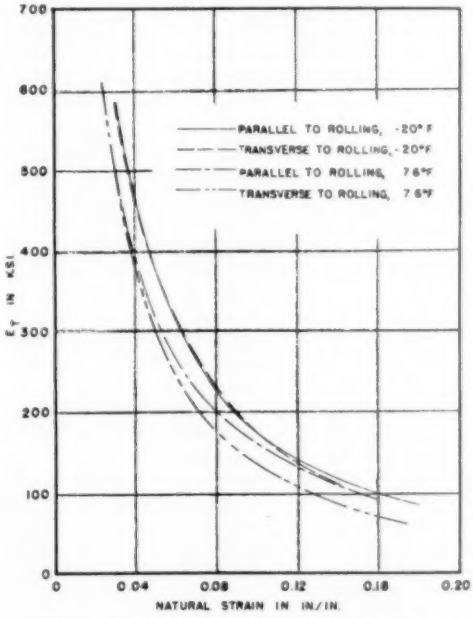
PARALLEL TO ROLLING, -20° F
TRANSVERSE TO ROLLING, -20°F
PARALLEL TO ROLLING, 76°F
TRANSVERSE TO ROLLING, 76°F
E_T IN KSI
NATURAL STRAIN IN IN./IN.

Fig. 6 Plot of E_T as a function of natural strain

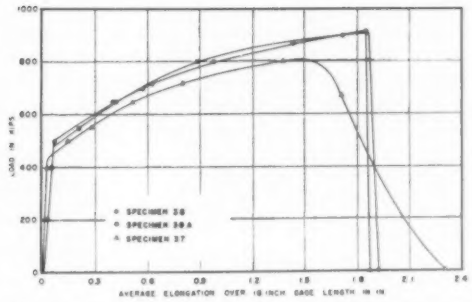

Fig. 7 Load-average elongation curves for plates with square opening with rounded corners

91% cleavage. The load-average elongation curves in Fig. 7 indicate that the over-all behavior of Spec. No. 38 at a temperature of −20° and of Spec. No. 38A at 0° was essentially identical and that both underwent more elongation to ultimate load than Spec. No. 37 and almost as much elongation to failure. The predominantly cleavage fracture in the two low-temperature tests was initiated by a small portion of shear fracture. The probable explanation for this behavior may be that the stress-raising effect of the 1⅛ in. radius at the corner of the opening was not sufficiently severe to initiate a cleavage fracture at a temperature of −20°, but the crack which formed as failure began was.

2. *Computation of the Unit Strain Energy Distribution by the Octahedral Theory*

A brief description of the octahedral theory for computing the unit energy absorption in the plastic range of the material was presented in a previous section of this paper. The elongation readings from the slide-wire resistance gages on Specs. Nos. 37 and 38 and the unit energy absorption in the calibration tensile tests were applied in the following manner to determine the unit energy absorption at various points in the large plates with openings:

1. From the elongation readings on the surface of Specs. Nos. 37 and 38, the natural strain values, ϵ_x and ϵ_y, were computed for each gage length.
2. Equation 5 was used to transform these natural strain values into the form of octahedral shear strains.
3. For each value of the octahedral shear strain found in Step 2, the corresponding unit strain energy absorption was read from Fig. 5.
4. The values from Step 3 were plotted on the surface of the specimens and unit strain energy contours drawn.
5. The volume under the surface representing the unit strain energy absorption at various points was equal to the total energy absorption within the gaged area and was compared with the energy absorption found for the same region from the load-average elongation curve in Fig. 7.

Typical unit strain energy contour maps for Spec. No. 37 at two different loads are shown in Figs. 8 and 9 and for Spec. No. 38 in Figs. 10 and 11. The pattern of the unit energy distribution which developed at the lower loads in the plastic range, changed somewhat as the ultimate load was approached. At the lower loads, the highest unit energy absorption was found at the corners of the opening and in the two regions extending diagonally upward from the corners of the opening to the outer edge of the plates, the regions where elastic stress theory would predict the highest values of the principal tensile stress. At the higher loads, the unit energy absorption was highest in the region of the least cross-section area. The highest unit energy absorption was found at the tangent point between the corner arc and the vertical side of the opening, the point where elastic stress theory would predict the maximum elastic principal tensile stress. The maximum value at this point was 18,300 in.-lb. per cubic inch for Spec. No. 37 and 20,000 in.-lb. per cubic inch for Spec. No. 38. These maximum values should not be taken as the absolute maximum for the specimens, because they represent the average value within a 1-in. gage length adjacent to the edge of the opening. Fracture began at the tangent point where the maximum energy absorption was observed.

When the unit energy values on the contour maps in Figs. 8 to 11, inclusive, were integrated, all with similar plots for other loads, the total energy absorbed within the gaged area was determined and compared with the total energy absorption computed from the load-average elongation curves in Fig. 7. The following table gives the results of this comparison:

Load, lb.	*Total energy absorption in in.-lb. From octahedral theory*	*Total energy absorption in in.-lb. From load-average elongation curve*
Spec. No. 37 at temperature of 76° F.		
500,000	79,400	60,600
650,000	243,000	270,000
720,000	426,000	452,000
800,000	1,056,000	884,000
Spec. No. 38 at temperature of −20° F.		
500,000	71,500	21,000
650,000	282,850	225,000
720,000	444,450	370,000
800,000	683,800	638,000
870,000	1,103,800	1,021,000
915,000	1,450,150	1,389,000

An examination of these values indicates that the agreement between the values of the energy absorption was better at intermediate and high loads than at low loads. At the lowest load of 500,000 lb. many of the elongation readings were of about the same magnitude as the sensitivity of the slide-wire resistance gages.

3. *Rate of Increase of Unit Energy Absorption*

The plots of the unit strain energy contours for Specs. Nos. 37 and 38 indicated that the unit energy absorption increased more rapidly in some portions of the specimens than in others, as the applied load was in-

creased. The manner of this increase was analyzed to determine whether it followed any consistent pattern for any one specimen and whether the behavior of the two plates was in any way similar.

The unit energy absorption U at each point on the specimen was plotted against the applied load P. The upper diagrams in Fig. 12 show typical examples of the plots made at every one of the 124 points on each specimen as well as the plot of the average unit energy absorption for the whole specimen. The shape of the plot for each point was in general the same as for the average energy absorption for the whole plate. It was

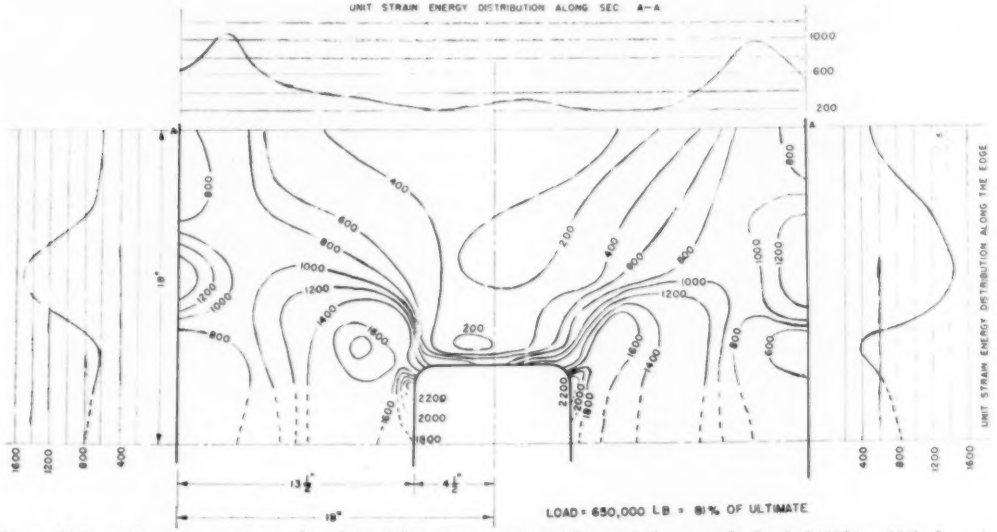
UNIT STRAIN ENERGY DISTRIBUTION ALONG SEC A-A
1000
600
200
UNIT STRAIN ENERGY DISTRIBUTION ALONG THE EDGE
LOAD = 650,000 LB = 81% OF ULTIMATE

Fig. 8 Unit strain energy contours for plate with square opening with rounded corners for load of 650 kips, 81% of maximum load. Spec. No. 37. Temperature 76° F.

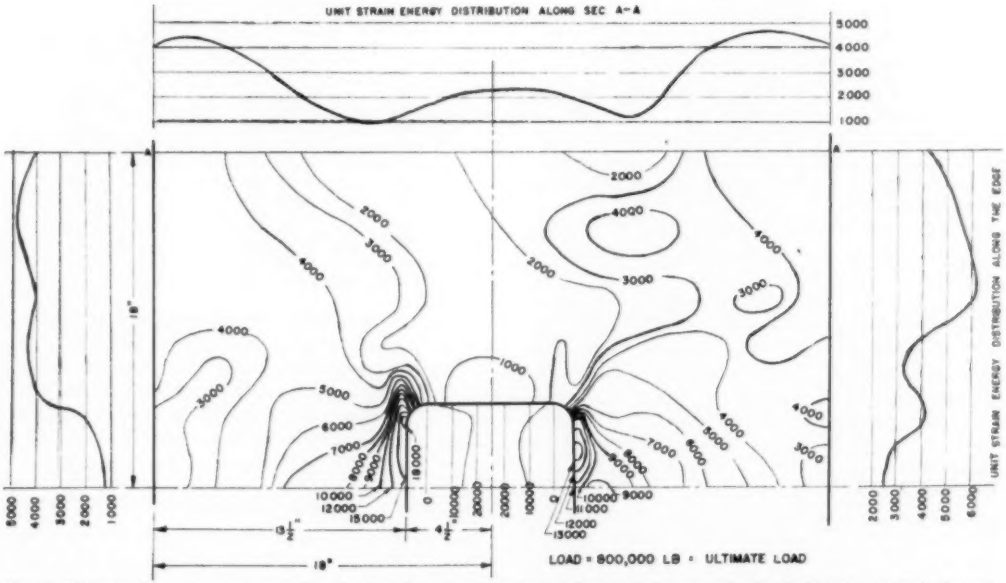

Fig. 9 Unit strain energy contours for plate with square opening with rounded corners for load of 800 kips, 100% of maximum load. Spec. No. 37. Temperature 76° F.

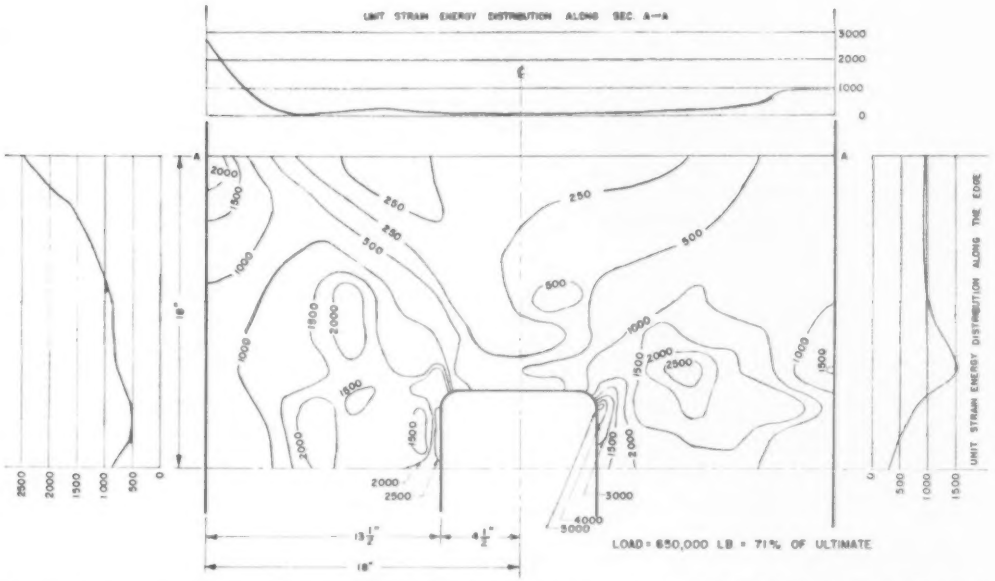

Fig. 10 Unit strain energy contours for plate with square opening with rounded corners for load of 650 kips, 71% of maximum load. Spec. No. 38. Temperature − 20° F.

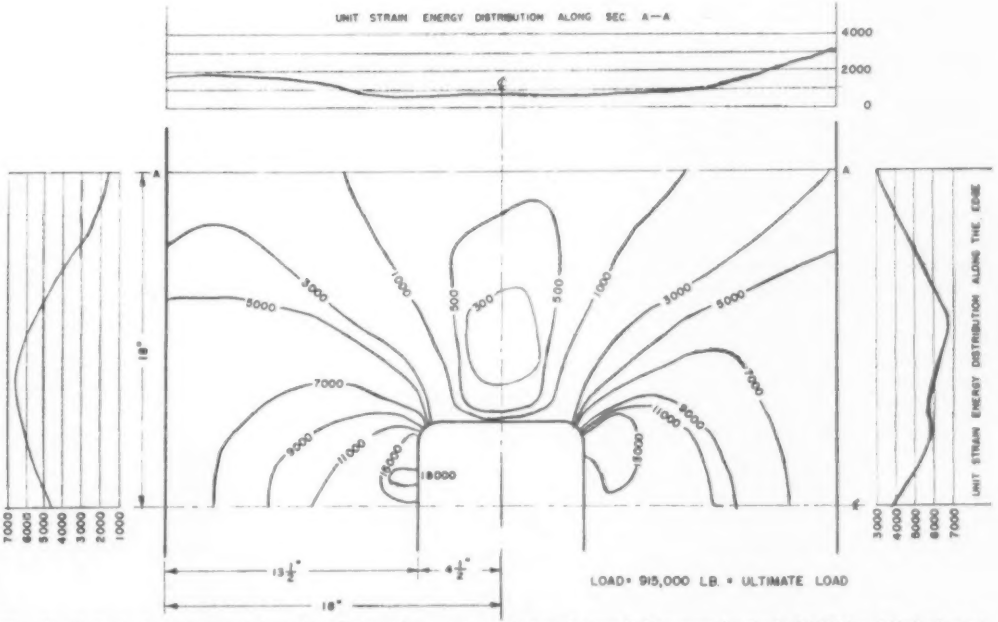

Fig. 11 Unit strain energy contours for plate with square opening with rounded corners for load of 915 kips, 100% of maximum load. Spec. No. 38. Temperature − 20° F.

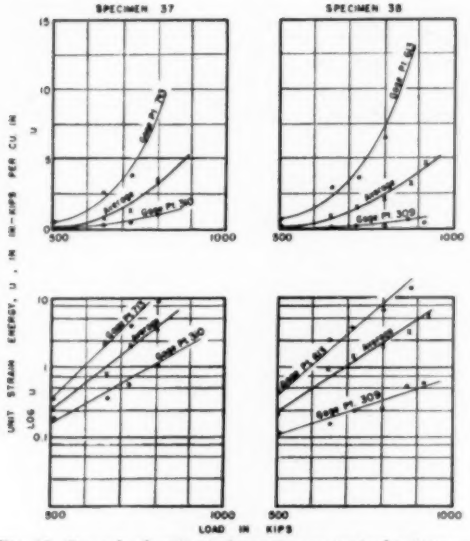

Fig. 12 Growth of unit strain energy at typical points on specimens under applied load. Specs. Nos. 37 and 38

found that the relation between the logarithm of the unit energy absorption and the applied load was linear, as shown in the lower diagrams of Fig. 12. The general equation of these semilogarithmic plots was of the form,

$$U = e^{A+BP} \qquad (12)$$

where A determines the intercept of the curve on the unit strain energy axis, B expresses the rate at which the unit strain energy increases and P is the applied load. It was observed in these tests that there was an insignificant variation of the value of A in the many plots and that the exponent B largely determined the magnitude of the unit energy value. Accordingly, the rate at which the unit strain energy increased at the various points on the specimen was analyzed by computing the value of the exponent B.

Since the exponent B is the slope of the semilogarithmic plot, a comparison of the rates of increase of the unit strain energy at the different points was made by comparing these slopes. When the slope of the average unit strain energy absorption for the whole specimen was termed $B_{av.}$ and the slope at any point n as B_n, the ratio, $B_n/B_{av.}$ expressed the relative rate of unit strain energy increase. This relative rate of increase was computed for all points. Figures 13 and 14 show contour lines connecting the points at which the values of the ratio $B_n/B_{av.}$ were equal. Where the rate of increase was equal to or greater than the average value, the contours are full lines. Where the rate was smaller, the contours are dashed lines.

The rate of increase of the unit strain energy was greater than the average rate for the whole specimen in the trapezoidal-shaped area on either side of the opening in the two specimens, that is, in the region of the least cross-section area, and smaller in the region above the opening. The greatest rate of increase was found at the corners of the opening and the least rate in the area just above the close opening to the vertical center line of the specimen.

The total energy absorption was almost the same at the same loads for Specs. Nos. 37 and 58, which were identical specimens. Therefore, when the plot of the rate of increase of unit strain energy in Fig. 13 is compared with that of Fig. 14, the values in one diagram may be considered to be directly relative to those in the other. A comparison of the contours in these two figures reveals the following points of interest:

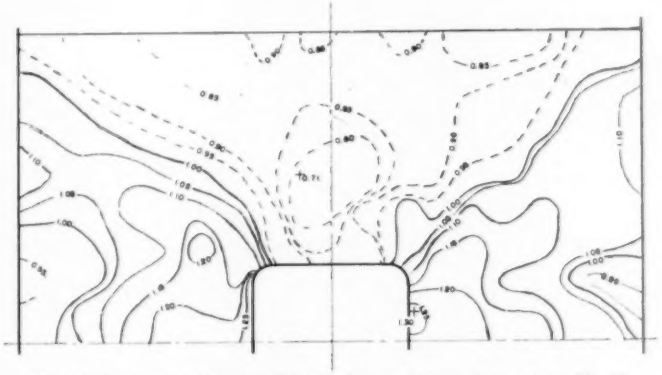

Fig. 13 Contours of the equal rates of energy absorption. Spec. No. 37

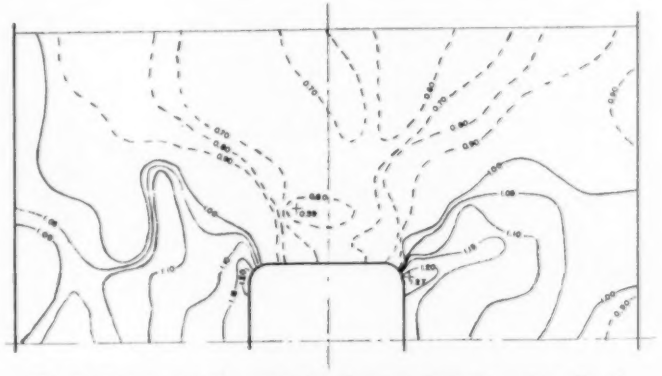

Fig. 14 Contours of the equal rates of energy absorption. Spec. No. 38

1. The areas of high and low values were more spread out in the case of Spec. No. 37 tested at 76° F. than in Spec. No. 38 tested at −20° F. The area in which the values of the rate of increase were greater than unity was 46% of the gaged area in the former specimen and 36% in the latter.

2. The values of the rate of increase varied from 0.71 to 1.30 for the room-temperature test and from 0.59 to 1.27 for the low-temperature test. While the maximum rate of increase was almost equal for the two tests, the range of variation was greater for the low-temperature specimen. The gradient of the rate of increase was steeper in the test at the lower temperature.

It must be remembered in comparing the numerical values of the contours in Figs. 13 and 14 that they are exponential values and that the variation from the minimum to the maximum value represents quite a large difference in the energy absorption.

4. *Computation of the True Stress Distribution on Transverse Cross Sections at the Ultimate Load*

The true stresses at ultimate load on the same four transverse cross sections of Specs. Nos. 37 and 38 were computed by the use of Equations 10 and 11 in Section III of this report and the data of the true stress-strain curves presented in Figs. 4 and 6. The experimentally determined values of Poisson's ratio were also used. The true stress distribution in the axial, or vertical, direction of the specimen computed on these four cross sections is shown for Spec. No. 37 in Figs. 15 to 18, inclusive, and for Spec. No. 38 in Figs. 19 to 22, inclusive. The actual or true thickness of the plate and the force per lineal inch of the actual plate width are given in these figures also.

If these stress distributions are examined in a general

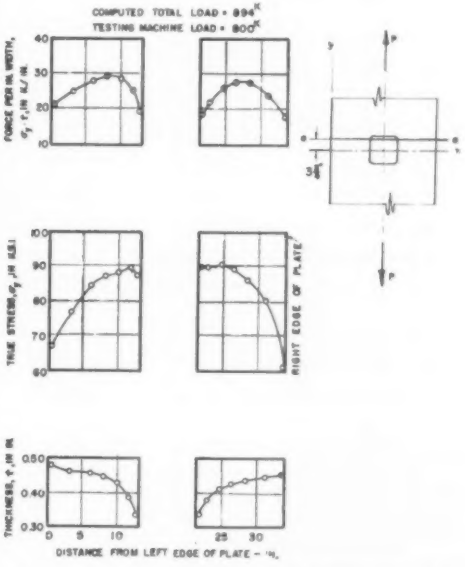
COMPUTED TOTAL LOAD = 894K
TESTING MACHINE LOAD = 800K
FORCE PER IN. WIDTH, σy t, IN K./IN.
TRUE STRESS, σy, IN K.S.I.
RIGHT EDGE OF PLATE
THICKNESS, t, IN IN.
DISTANCE FROM LEFT EDGE OF PLATE – IN.

Fig. 15 Distribution of true thickness, axial true stress and force per inch for transverse section a-a at maximum load of 800 kips. Spec. No. 37

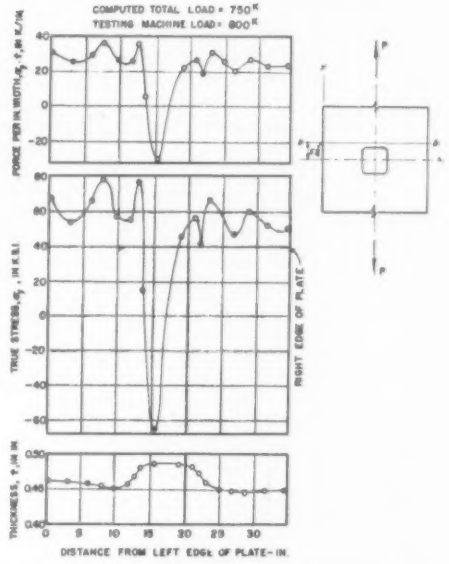
COMPUTED TOTAL LOAD = 750K
TESTING MACHINE LOAD = 800K
FORCE PER IN. WIDTH, σy t, IN K./IN.
TRUE STRESS, σy, IN K.S.I.
RIGHT EDGE OF PLATE
THICKNESS, t, IN IN.
DISTANCE FROM LEFT EDGE OF PLATE – IN.

Fig. 16 Distribution of true thickness, axial true stress, and force per inch width for transverse section b-b at maximum load of 800 kips. Spec. No. 37

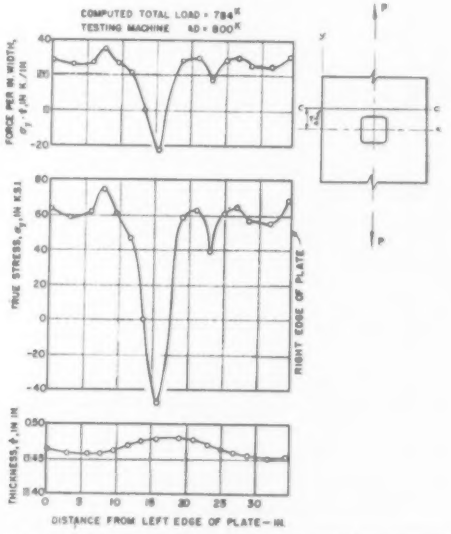
COMPUTED TOTAL LOAD = 784K
TESTING MACHINE LOAD = 800K
FORCE PER IN. WIDTH, σy t, IN K./IN.
TRUE STRESS, σy, IN K.S.I.
RIGHT EDGE OF PLATE
THICKNESS, t, IN IN.
DISTANCE FROM LEFT EDGE OF PLATE – IN.

Fig. 17 Distribution of true thickness, axial true stress, and force per inch width for transverse section c-c at maximum load of 800 kips. Spec. No. 37

way, it may be seen that their pattern was similar to that which would occur under elastic stresses. The stress distribution in the region of the opening was nonuniform with the highest values of the tension stress near the corner. On the cross sections more remote from the opening, the stress distribution became more nearly uniform, but was still far from uniform. Low tensile stresses or even compression stresses were present in the area just above the opening. The pattern of the stress distribution in Specs. Nos. 37 and 38 was much the same, but the values of the true stresses in the latter were higher than in the former specimen because of the higher load which was being applied.

The correctness of the individual stress values can be surmised only intuitively. In the calibration tensile tests, the average true stress at which necking began was 75,500 psi. in the tests at 76° F. and 81,600 psi. in the tests at −20° F. The average true stress at fracture was 122,500 psi. in the former tests and 115,400 psi. in the latter. The maximum true stresses plotted in Figs. 15 to 22 were of the same order of magnitude as these true stresses found in the calibration tensile tests. Their magnitudes were also such as might be expected in a notched plate at its ultimate load.

It is interesting that the maximum values of the true tensile stress occurred in the regions where the greatest unit energy absorption was found. The fracture in both specimens was initiated in the corner of the opening where the highest values of the energy absorption and the true stress appeared.

An indirect method of checking these true stress values is to sum up the stresses on different transverse cross sections of the specimen to obtain the total applied force. A comparison of the values of the total load found by integrating the upper curve in Figs. 15 to 22, the diagram which shows the force per lineal inch of

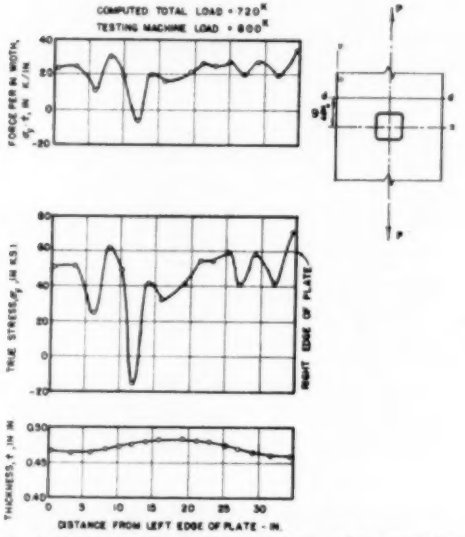
COMPUTED TOTAL LOAD = 720^K
TESTING MACHINE LOAD = 800^K
FORCE PER IN WIDTH, $\sigma_y \cdot t$, IN K/IN
TRUE STRESS, σ_y, IN K.S.I.
THICKNESS, t, IN IN.
RIGHT EDGE OF PLATE
DISTANCE FROM LEFT EDGE OF PLATE - IN.

Fig. 18 Distribution of true thickness, axial true stress and force per inch for transverse section d-d at maximum load of 800 kips. Spec. No. 37

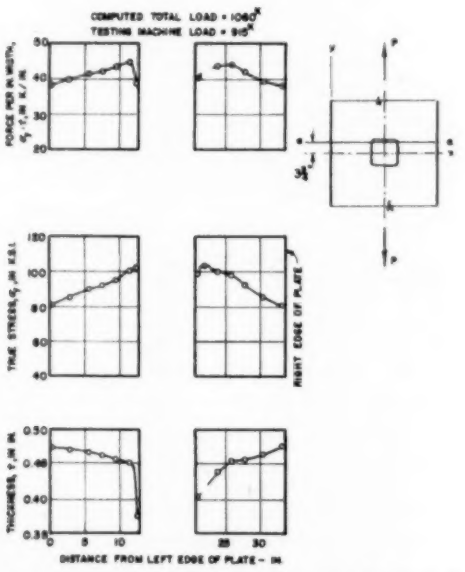
COMPUTED TOTAL LOAD = 1060^K
TESTING MACHINE LOAD = 915^K
FORCE PER IN WIDTH, $\sigma_y \cdot t$, IN K/IN
TRUE STRESS, σ_y, IN K.S.I.
THICKNESS, t, IN IN.
RIGHT EDGE OF PLATE
DISTANCE FROM LEFT EDGE OF PLATE - IN.

Fig. 19 Distribution of true thickness, axial true stress and force per inch for transverse section a-a at maximum load of 915 kips. Spec. No. 38

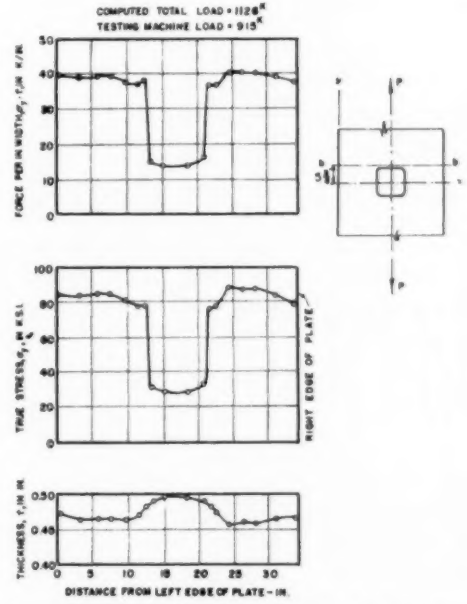
COMPUTED TOTAL LOAD = 1126^K
TESTING MACHINE LOAD = 915^K
FORCE PER IN WIDTH, $\sigma_y \cdot t$, IN K/IN
TRUE STRESS, σ_y, IN K.S.I.
THICKNESS, t, IN IN.
RIGHT EDGE OF PLATE
DISTANCE FROM LEFT EDGE OF PLATE - IN.

Fig. 20 Distribution of true thickness, axial true stress and force per inch for transverse section b-b at maximum load of 915 kips. Spec. No. 38

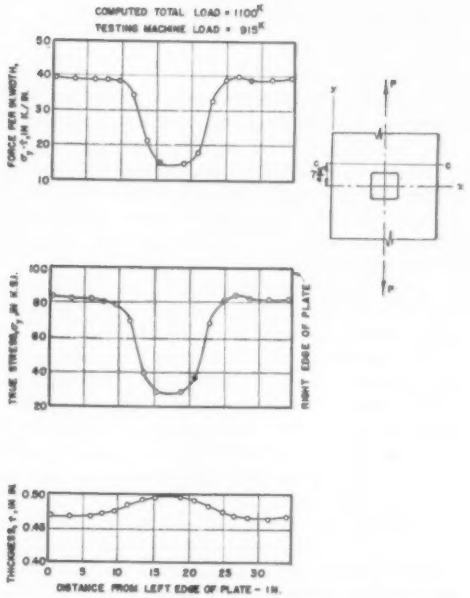
COMPUTED TOTAL LOAD = 1100K
TESTING MACHINE LOAD = 915K
FORCE PER IN WIDTH, $\sigma_y t$, KIPS PER IN.
TRUE STRESS, σ_y, KSI
RIGHT EDGE OF PLATE
THICKNESS, t, IN IN.
DISTANCE FROM LEFT EDGE OF PLATE - IN.

Fig. 21 Distribution of true thickness, axial true stress and force per inch for transverse section c-c at maximum load of 915 kips. Spec. No. 38

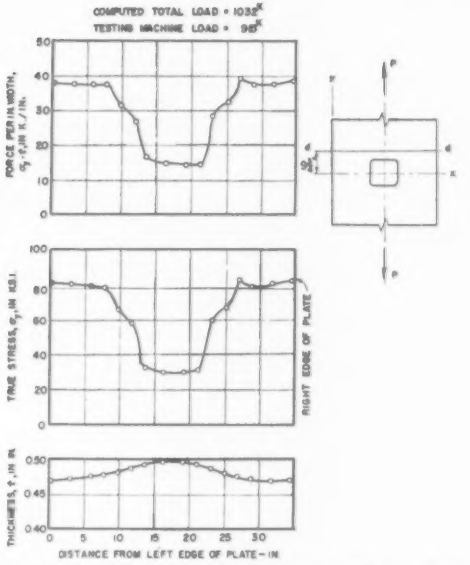
COMPUTED TOTAL LOAD = 1032K
TESTING MACHINE LOAD = 943K
FORCE PER IN WIDTH, $\sigma_y t$, KIPS PER IN.
TRUE STRESS, σ_y, KSI
RIGHT EDGE OF PLATE
THICKNESS, t, IN IN.
DISTANCE FROM LEFT EDGE OF PLATE - IN.

Fig. 22 Distribution of true thickness, axial true stress and force per inch for transverse section d-d at maximum load of 915 kips. Spec. No. 38

plate width, with the actual testing machine load at ultimate load is as follows:

Cross section	*Computed total load, lb.*
Spec. No. 37 at temperature of 76° F., load of 800,000 lb.	
a-a	894,000
b-b	750,000
c-c	784,000
d-d	720,000
Spec. No. 38 at temperature of −20° F., load of 915,000 lb.	
a-a	1,060,000
b-b	1,126,000
c-c	1,100,000
d-d	1,032,000

Reasonably good correlation was found between the values of the total load derived from the computed values of the true stresses and the actual testing machine load.

VII. SUMMARY AND CONCLUSIONS

Two methods of analysis of plastic flow, the octahedral theory for computing the unit energy absorption and a method developed in the course of this investigation for computing true stresses, were applied in the case of two large plates with square openings with rounded corners. The first failed with a completely shear fracture at a temperature of 76° F. and the second with a fracture 91% cleavage at a temperature of −20° F. Both methods of analysis utilized the experimental strain data from these tests.

From the limited application of the octahedral theory made in this investigation, it was found that this method of analysis gave unit energy distributions, which, when integrated, produced values of the total energy absorption that agreed fairly closely with the energy absorption determined from the load-average elongation curve. This method presents a dependable, though laborious means of studying plastic flow and fracture in structural members. These conclusions are essentially those which resulted from an earlier application of the method.[3]

The two specimens absorbed approximately the same amounts of energy at the same loads up to the ultimate load, although one failed with a completely shear fracture and the other with a fracture almost completely cleavage. However, the gradient of the rate of increase of the unit strain energy was steeper in the latter than in the former and the greater part of the total energy was absorbed in a smaller portion of the specimen.

The method of computing true stresses in the plastic range of the material was applied for the first time and gave results which correlated reasonably well with the observed data. The method would not work well in the so-called "flat" portion of the stress-strain curve and, at stresses in the range where necking of the material is occurring, would be subject to some interpretation, since Poisson's ratio has an anomalous meaning, if applied in this range. Further applications of the method are required to test its reliability.

VIII. SYMBOLS

U = unit strain energy, in.-lb. per cubic inch.
τ = octahedral shear stress, psi.
γ = octahedral shear strain.
x, y = coordinate axes, the rolling direction and the applied tensile force are parallel to the y-axis.
z = coordinate axis perpendicular to the plate.
$\sigma_x, \sigma_y, \sigma_z$ = true stresses, psi.
$\epsilon_x, \epsilon_y, \epsilon_z$ = natural strains.
$\delta_x, \delta_y, \delta_z$ = true stresses from an experimental true stress-strain diagram, psi.
$\epsilon_x, \epsilon_y, \epsilon_z$ = natural strains from an experimental true stress-strain diagram.
$E_{\tau x}, E_{\tau y}$ = tangent moduli as determined from the true stress-strain diagram in the x- and y-direction, psi.
β_x, β_y = intercepts of the tangent to the true stress-strain diagram on the natural strain axis.
μ_{xy}, μ_{yx} = Poisson's ratio in this report is interpreted in terms of natural strains:

$$\mu_{xy} = \frac{\epsilon_y}{\epsilon_x}$$

e = base of the natural logarithm.
P = applied axial force, kips.
A = intercept on the u-axis of a semilogarithmic plot of u against the applied force P.
B = slope of a semilogarithmic plot of u against the applied force P.

IX. ACKNOWLEDGMENTS

The investigation reported herein was sponsored by the Ship Structure Committee and was carried out in the Structural Research Laboratory of the Department of Civil Engineering, University of Washington. The test program and the preparation of the report were under the direction of Dr. R. A. Hechtman, Associate Professor of Structural Research. Dr. D. Vasarhelyi was project engineer and was assisted by K. J. Kenworthy and Y. T. Yoshimi, graduate research fellows, and R. B. Matthieson, computer and draftsman.

The authors wish to express their appreciation to John Vasta of the Bureau of Ships, Department of the Navy, and Dr. Finn Jonassen of the National Research Council.

References

1. Vasarhelyi, D., and Hechtman, R. A., "Welded Reinforcement of Openings in Structural Steel Members," THE WELDING JOURNAL, *Research Suppl.*, **XVI**, 182-s to 192-s (1951).
2. Nadai, A., *Theory of Flow and Fracture of Solids*, McGraw-Hill, New York (1950).
3. Liu, S. I., and Carpenter, S. T., "A Study of Plastic Deformation and Fracturing by Strain Energy Distribution," Serial No. SSC-38, Ship Structure Committee, 1950.

Discussion by Samuel T. Carpenter

The authors state that the two specimens, No. 37 and No. 38, absorbed approximately the same amounts of energy at the same loads, although one failed with a ductile fracture and the other with a cleavage fracture. The energy values given for the two specimens do not bear out this statement. As a matter of record they are not closely equal, and at the higher equal loads, specimen No. 38 which failed in cleavage, had the higher energy absorption.

It is not altogether surprising that specimen No. 38, tested at −20° F. had a greater ultimate strength and energy absorption to maximum load than specimen No. 37 tested at 76° F. An increase in ultimate tensile stress as temperature is lowered, is shown by tests on ASTM standard tensile bars. Also, tests conducted recently at Swarthmore College indicate that strength and energy absorption need not be relatively impaired by a cleavage fracture at a lower test temperature if the acuity of the notch is that of a circular curve of large radius. In fact, transition temperature could not be determined from the curves of energy to maximum load plotted against temperature due to the absence of the characteristic discontinuity in the transition temperature zone.

It appears to the writer that equations 6 and 7, expressing the strains at a point in a plastic plane stress problem may be assumed to be approximate only if $\mu_{yx}\beta_y$ and $\mu_{yx}\beta_x$ are small. These latter two expressions should be added respectively to the right hand side of Equations 6 and 7.

The writer believes that it is not essential to extend the data to final load distributions as the unit energy absorption contours are far more descriptive. When the material at a local point has absorbed its maximum unit energy, at a given temperature, fracture will occur. Comparisons of various specimen geometries can be made on this basis alone.

Samuel T. Carpenter, Dept. of Civil Engineering, Swarthmore College.

Discussion by Captain W. P. Roop

The "derivation" of Section III assumes a stress-strain curve of the linear form as shown in Fig. 1. But in Fig. 4 the stress on the assumption is, in a typical case of 10% strain, 90 kipsi. instead of the observed 70. Is this error negligible?

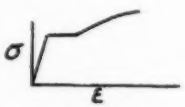

Figure 1

Captain W. P. Roop, U.S. Navy (Ret.)

Other assumptions also hold only outside the region of high strain. That, however, is the most, perhaps the only, important region. Are we to write off everything in the report referring to it?

I do not see how Section III helps in obtaining Fig. 5, but in any case we should know whether Fig. 5 is subject to the errors above mentioned at higher strain values. On what is the statement at the end of Section III based, that the method "involves little approximation?"

It is, however, encouraging to find efforts made to extend the study of strain distributions. Accepting the results of Figs. 8 and 11, we note that the highest localizations are of the same order as in the acutely notched Swarthmore plates. The difference lies in the extent and disposition of the region of high strain.

The *average* unit energy absorbed seems, as would be expected, higher over the whole specimen than in the presence of an acute notch, but no data on this have been seen. A value of about 2000 in.-lb. per inch cube seems to have been attained.

The energy values presented refer only to conditions at maximum load and at various stages on the way there. Fracture received no consideration, although I believe that close scrutiny of the points of highest concentration would reveal incipient cracks. If not would the authors please say so?

Since time elapsed between the stages of loading, enough to permit measuring up the grids, aging may have made the results different from what would have been found in steady advance without interruption.

The curves of local strain on load may have some significance, and it would be interesting to have the authors' further comment on them.

In Fig. 12 it appears that the different curves nearly coincide, but that the difference between the two specimens lies mainly in the distance traversed up this ascent before maximum load is attained. This raises the question as to how two identical specimens tested at different temperatures shall be judged to be at equivalent stages in progress toward fracture. It is often supposed that the stage of maximum load is somehow equivalent in such different specimens if they traverse the same load-elongation curve, differing only in the points at which they break off.

But in the present case we see the anomaly that the colder (and hence more brittle) specimen absorbs half again as much energy before maximum load as the ductile one. Is this just a matter of more strength? The authors' comment will be read with interest.

Discussion by M. J. Letich

The authors are to be congratulated for their efforts in attempting to translate laboratory test data into results that may be more broadly useful. It is true that even following these additional interpretations the results can not be considered of immediate practical application, but they definitely represent a step in the right direction.

An attempt to utilize the experimentally obtained grid data from two plates containing rectangular openings, one tested at room temperature and the other at $-20°$ F. to determine the unit strain energy distribution by the octahedral theory, is indeed a worth-while undertaking that may set an interpretative pattern for future investigations of this nature.

A previous application of this method by S. I. Liu and S. T. Carpenter[1] on the plastic deformation of two internally notched steel plates under axial tension yielded results which checked with measured values. In this study it was noted that unfortunately the grid measurements took so long that about a week elapsed between unloading and reloading, and in consequence strain aging became an important and disturbing factor. By comparison, in the present investigation only 40 min. were required for obtaining complete readings at a given load, using the rectangular grid system of horizontal and vertical slide wire resistance gages developed by the authors for this study. (These gages will be described in a future paper.)

The authors mention that the grid system covered one side of the specimen and only a portion of the other face of the plate. While it is true that this procedure greatly reduced the number of gages to be read, this reduction in the number of gages may have contributed to several anomalies noted. When comparing contours shown in Figs. 22 and 16, it is noted that irregular strain patterns are produced, probably due to buckling. Had complete grid systems been used on both sides of the specimens, thereby permitting average values to be used, the symmetrical distributions expected from the geometry of the specimen would undoubtedly have been possible. In connection with the interpretation of strain data, it is not clear whether the sagitta gage readings were used to correct the contours of Specimen 37.

In the application of the octahedral theory to the problem of plastic deformation, the equations used by the authors are based on the following necessary assumptions:

1. That the material behaves isotropically throughout the plastic range.
2. That the directions of the principal stresses and of the principal strains coincide at all times.
3. That the entire strain energy is distortional energy, i.e., the volume of the deformed body remains constant.

The only value of Poisson's ratio in both directions that will satisfy assumptions 1 and 3 is 0.5. The discusser is at a loss to understand why it was felt that the experimental determinations of this ratio were deemed necessary. The experimental values of the Poisson ratio determined at 76° F. for both the axial and transverse directions of the specimen varied only by about 6%. Within reasonable experimental area, all values determined are close to 0.5, and for the sake of simplicity that value could have been used in all calculations.

M. J. Letich, American Bureau of Shipping.

[1] See Bibliography.

The method of analysis presented by the authors, although laborious, appears to be a most useful method for studying the plastic behavior to fracture of structural members containing discontinuities or notches. Its present application to two identical plate specimens having square openings with rounded corners and tested at −20° and 76° F. showed no appreciable difference in energy absorbed. To demonstrate the complete validity of the method, it must be applied to specimens showing full-brittle failure. This will require a very low testing temperature, particularly for the 1/4 in. thick specimens. If this is not possible, the method should be applied to thicker specimens tested at sufficiently low temperatures to obtain brittle failures.

Authors' Closure

The criticism and the suggestions of the discussers are very much appreciated. Since the whole approach to the study of the plastic deformations is still in the exploratory state, any idea different from those presented by the authors may open up new aspects of the problem and point to better ways to the solution.

The fact that the energy absorption of Specimens No. 37 (76° F.) and No. 38 (−20° F.) fall closely within the same range at the same loads, may have been given undue emphasis by the authors, as Professor S. T. Carpenter points it out. However, his statement that "at the higher equal loads, Specimen No. 38 which failed in cleavage had the higher energy absorption" is only partly correct if one examines the energy values obtained by the octahedral theory and is completely reversed if one accepts the energy values obtained from the area under the load-elongation curve. In the authors' viewpoint, the application of the octahedral theory yields total energy values which are somewhat approximate, as any computation of energy or stress in the plastic range will be, while the total energy obtained from the load-elongation curve may be a better basis of comparison.

It should have been pointed out in the paper, that the terms $\mu_{zx}\beta_y$ and $\mu_{xy}\beta_z$ in Equations 6 and 7 were neglected. The final results obtained by the formulae seem to justify this process, although it is hard to verify theoretically by what circumstances the above mentioned members are "small enough." Moreover, if these terms should be considered sufficiently large to be included in Equations 6 and 7, it should be noted that they would ultimately disappear in the conversion of Equations 8 and 9 into the form given in Equations 10 and 11.

The results of a few other tests, both prior and subsequent to those described in this paper have given stress distributions which further tend to bear out the applicability of Equations 10 and 11 to problems of plastic flow in structural steel where the stress levels lie between the end of the so-called "flat portion" of the stress-strain curve and the stress at which local necking begins.

Professor Carpenter's remarks to the effect that cleavage fracture can follow a considerable energy absorption are most timely. It is unfortunate that the results of investigations such as the "wide plate tests" have been taken by many engineers to mean that cleavage fracture is always associated with a small energy absorption.

The authors are not ready to accept fully Professor Carpenter's remarks that "when the material at a local point has absorbed its maximum unit energy, at a given temperature, fracture will occur," when this statement is applied to welded members such as those tested in this investigation. Such a statement is still a hypothesis which tests such as these in sufficient quantity may someday substantiate. For this reason, the authors prefer to approach the problem of failure of welded structures from the standpoint of both maximum energy absorption and stress distribution.

No special attention has been paid to the value of *average* unit strain energy absorptions, since its local distribution was considered more significant.

The procedure used in measuring the surface strains on the plate specimens adequately provided for possible curvature of the plate during the test. In some regions of both specimens, the grid system was located on the two opposite faces of the specimens. In the remaining regions where the curvature during the test was expected to be of negligible amount, sagitta readings were taken.

The three assumptions which Mr. Letich refers to in his discussion were used in the derivation of the equations for the octahedral theory in its original form by A. Nadai. Poisson's ratio does not enter into this derivation. Only the second assumption is necessary for the derivation of the formulae for stress in Equations 10 and 11. Since the value of 0.5 for Poisson's ratio arises from the assumptions of theory and little information is available concerning its validity from an experimental standpoint, the authors thought it wise to determine whether any anisotropy developed by rolling of the steel plate during manufacture existed. The results of the present tests indicated that the assumption of a value of 0.5 for Poisson's ratio in future plastic stress computation is entirely justified.

The writers are aware of the excellent descriptive value of the unit strain energy contours as pointed out by Professor S. T. Carpenter as well as by Mr. M. J. Letich. Comments about the suggested manner of analyzing the rate of increase of unit strain energy absorption as presented in Figs. 13 and 14 of the paper would have been welcomed.

The authors do not clearly understand the nature of the question raised by Captain Roop in the first three paragraphs of his discussion. If it is thought that the true stress-strain curve has been assumed to be linear in the region between the end of the "flat portion" of the curve and the stress at which necking begins, the intent of Fig. 1 in the paper has been misunderstood. The intercept β is a varying one, different for each value

of the natural strain. Furthermore, the equations of stress in Section III of the paper were not used in the construction of Fig. 5, which instead was computed by the use of Equations 1, 2 and 3.

Since the strain data used in the computation of the energy distribution at maximum load by the octahedral theory were taken at the moment immediately after a very small shear fracture had been initiated, they do not include, in any significant degree, the energy necessary to the ductile propagation of a crack.

In closing, the authors thank all of the discussers for their contributions which add much to the value of the paper. Some of the comments of the discussers have arisen from a misunderstanding of the points presented in the original paper, a circumstance not surprising since the presentation of a considerable amount of information was necessarily made rather brief. It is hoped that those dealing with problems of plastic deformation of plates with openings or internal notches will find the information useful.

Fatigue Tests on Aluminum Alloy Spot-Welded Joints

A comparison of results of fatigue tests of spot-welded joints in sheets of various high-strength aluminum alloys

by Marshall Holt and E. C. Hartmann

INTRODUCTION AND OBJECT

FOR several years, the Aluminum Research Laboratories has been conducting a series of fatigue tests on lap joints made in strips of Alclad 0.064-in. thick sheet, each joint containing a single spot weld at the center of the lap. The purpose of these tests has been to evaluate and compare the fatigue strength of such joints made in sheet of various high-strength aluminum alloys. This paper presents the results of these tests and compares them with those from other investigations.

Marshall Holt and **E. C. Hartmann** are connected with the Aluminum Research Laboratories, Aluminum Company of America, New Kensington, Pa.

MATERIALS AND SPECIMENS

Alclad sheet of the alloys and tempers listed in Table 1 were used in these tests. The tensile properties given

Table 1—Mechanical Properties of Sheet Used in Fatigue Tests of Spot-Welded Joints

			Parallel to direction of rolling				*Normal to direction of rolling*			
Alloy and temper	*Thickness, in.*		*Tensile strength, psi.*	*Tensile yield strength (Offset = 0.2%), psi.*	*Elongation in 2 in., %*	*Compressive yield strength (Offset = 0.2%), psi.*	*Tensile strength, psi.*	*Tensile yield strength (Offset = 0.2%), psi.*	*Elongation in 2 in., %*	*Compressive yield strength, (Offset = 0.2%), psi.*
	Sheet	*Alclad coating†*								
Alclad 24S-T3	0.064	0.0016	68,800	51,700	20.5	...	66,850	44,400	19.0	...
Alclad 24S-T81*	0.064	0.0016	68,900	62,500	6.5	61,750	67,250	60,150	6.5	62,400
Alclad 24S-T36	0.066	0.0016	71,900	60,900	15.5	...	70,050	54,100	14.0	...
Alclad 24S-T86‡	0.068	0.0016	73,550	69,650	6.5	...	72,650	68,200	6.5	...
Alclad 75S-T6	0.064	0.0018	80,350	71,200	14.0	...	78,800	66,850	14.0	...
Alclad 14S-T4	0.064	0.0018	65,500	47,300	21.5	37,050	64,850	40,350	20.5	43,600
Alclad 14S-T6	0.064	0.0018	68,850	62,050	11.0	61,650	68,200	60,700	9.5	64,300

* Also tested as artificially aged after spot welding, 12 hr. at 375° F.
† Thickness of coating on each side.
‡ Also tested as artificially aged after spot welding, 8 hr. at 375° F.
All tensile tests made in accordance with ASTM Standard Methods of Tensile Testing of Metallic Materials (E8–46).

Table 2—Data on Spot Welds in Simple Lap Joints. Welds Made on D.-C. Stored-Energy Machine

Alloy and temper	Volts	Capacitance, mfd.	Energy, watts, sec.	Transformer ratio	0.625-in. diam. tips — Top	0.625-in. diam. tips — Bottom	Tip pressure, lb.*
Alclad 24S-T3	2430	2400	7,080	450:1	4-in. R	Flat	2700 + 1000
Alclad 24S-T81	2450	2400	7,200	450:1	4-in. R	Flat	2750 + 1000
Alclad 24S-T36	2450	2400	7,200	450:1	4-in. R	Flat	2750 + 1000
Alclad 24S-T86	2450	2400	7,200	450:1	4-in. R	Flat	2750 + 1000
Alclad 75S-T6	2470	2400	7,320	450:1	4-in. R	Flat	2850 + 1000
Alclad 14S-T4	2700	2600	10,000	302:1	3-in. R	Flat	2250 + 1000
Alclad 14S-T6	2670	2600	9,250	302:1	3-in. R	Flat	2500 + 1000

* Forging pressure applied 10 milliseconds after start of firing.
A chemical cleaning procedure was used to give less than 50-microhm faying-surface resistance.

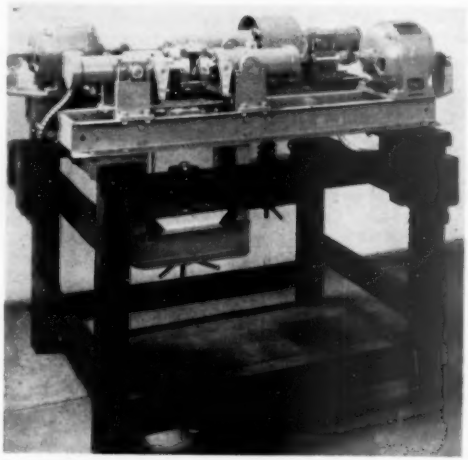

Fig. 3 (right) ARL rotating beam fatigue testing machine designed and built at Aluminum Research Laboratories in 1942. Shows adapters for maintaining alignment of fixtures while inserting specimen

compare favorably with the published values for the various materials and meet the respective specifications requirements. The artificially aged materials were obtained from the same lots of material as the corresponding naturally aged materials.

Data on the spot-welding technique used are given in Table 2. All welds were made with d.-c. stored-

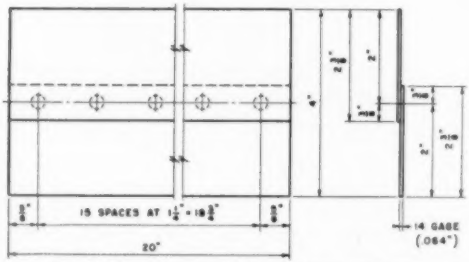

Fig. 1 Panel from which specimens were cut

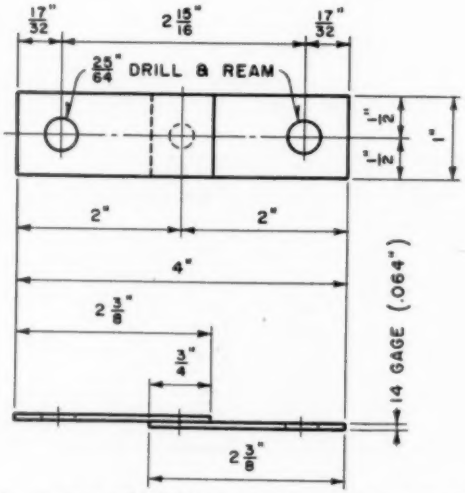

Fig. 2 Spot-welded fatigue specimen cut from panel shown in Fig. 1

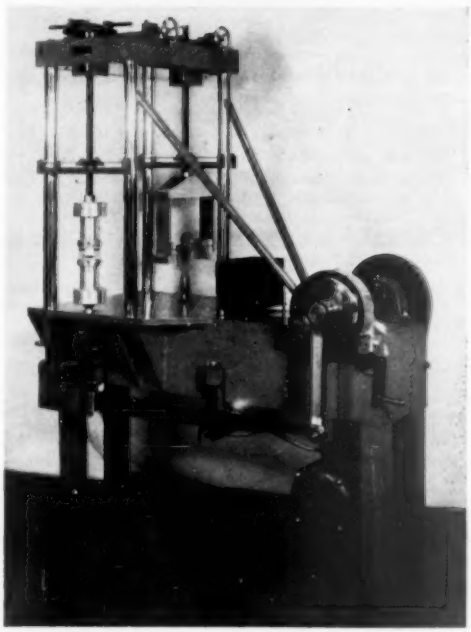

Fig. 4 Krouse direct-stress fatigue testing machine

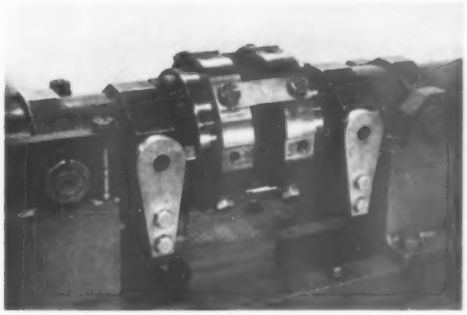

Fig. 5 Fixtures for loading joints in ARL rotating beam fatigue machine

energy equipment using procedures which can be considered commercial. The panels from which the individual specimens were cut were 20 in. long and consisted of two sheets of 0.064-in. thick material with an overlap of $^3/_4$ in. The spot welds were spaced $1^1/_4$ in. apart so the individual specimens, each containing a single spot, could be cut and machined to a width of 1 in. The panels and individual fatigue specimens were as shown in Figs. 1 and 2. The specimens for static test also contained a single spot weld but were somewhat longer than the fatigue specimens.

METHODS OF TESTING

Two different machines were used during the testing of the fatigue specimens and were found to give good agreement in check tests of identical specimens. The machines are shown in Figs. 3 and 4. The ARL rotating-beam fatigue machine shown in Fig. 3 was designed and built at the Aluminum Research Laboratories in 1942 and operates at 1750 rpm. It was used for most of the tests. The fixtures for testing a set of four specimens in this machine are shown in Fig. 5. During the test, the fixtures and specimens formed part of a rotating beam, the central portion of which was subjected to a uniform bending moment. The spot welds were thus subjected to a cyclic shearing load which varied from a maximum in one direction to the same value in the opposite direction (completely reversed stress).

A Krouse direct-stress fatigue machine having a

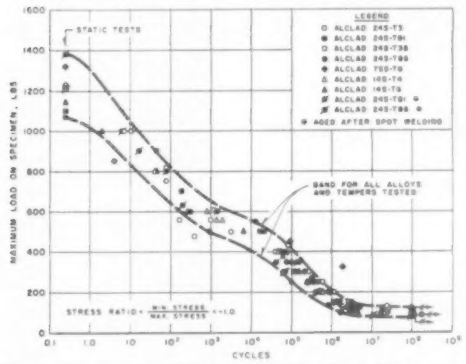

Fig. 6 Summary of all fatigue test data from this investigation

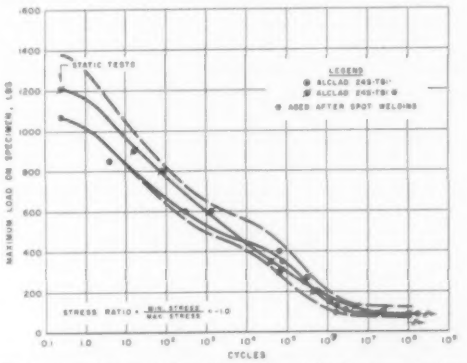

Fig. 8 Results for Alclad 24S-T81, artificially aged before and after spot welding

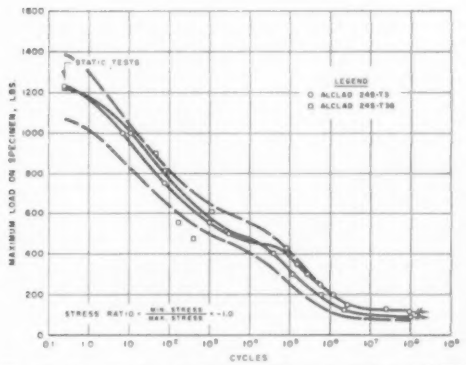

Fig. 7 Results for Alclad 24S-T3 and Alclad 24S-T36

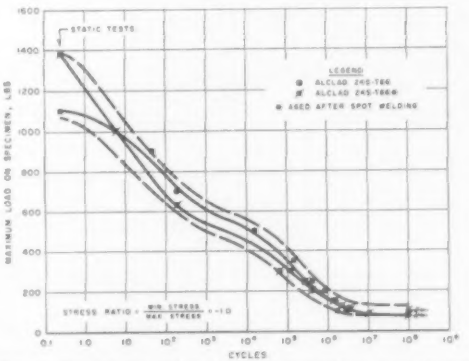

Fig. 9 Results for Alclad 24S-T86, artificially aged before and after spot welding

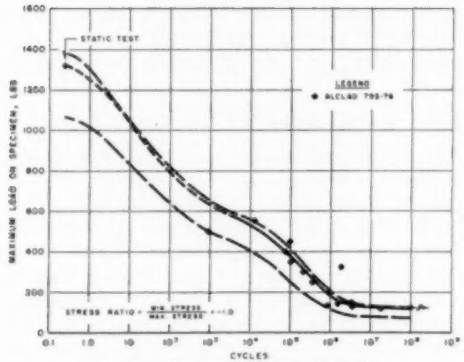

Fig. 10 Results for Alclad 75S-T6

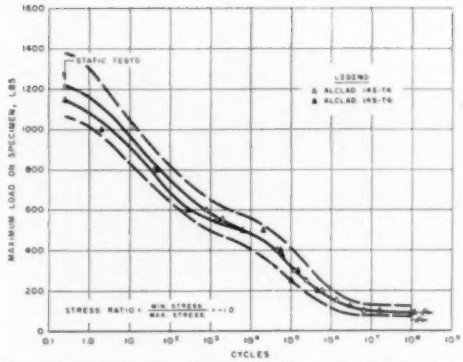

Fig. 11 Results for Alclad 14S-T4 and Alclad 14S-T6

maximum capacity of 5000 lb. is shown in Fig. 4. This machine is also provided with fixtures for testing a set of four specimens. It operates at 1500 cpm. Although this machine is adjustable to give any desired loading cycle, the tests were made with completely reversed stresses.

Each of these machines is equipped with a limit switch which automatically stops the machine when a specimen fails. Each also has a counter for determining the number of cycles of load. The tests in which the expected life of the specimens was less than about 1000 cycles were made in the Krouse machine, with the machine operated by hand and the number of cycles counted.

Usually only one of the four joints failed in fatigue and the assembly then collapsed. Occasionally it was difficult to determine the location of the initial failure, whether in the spot weld or sheet, because the joints were mutilated considerably by the time the machine came to rest.

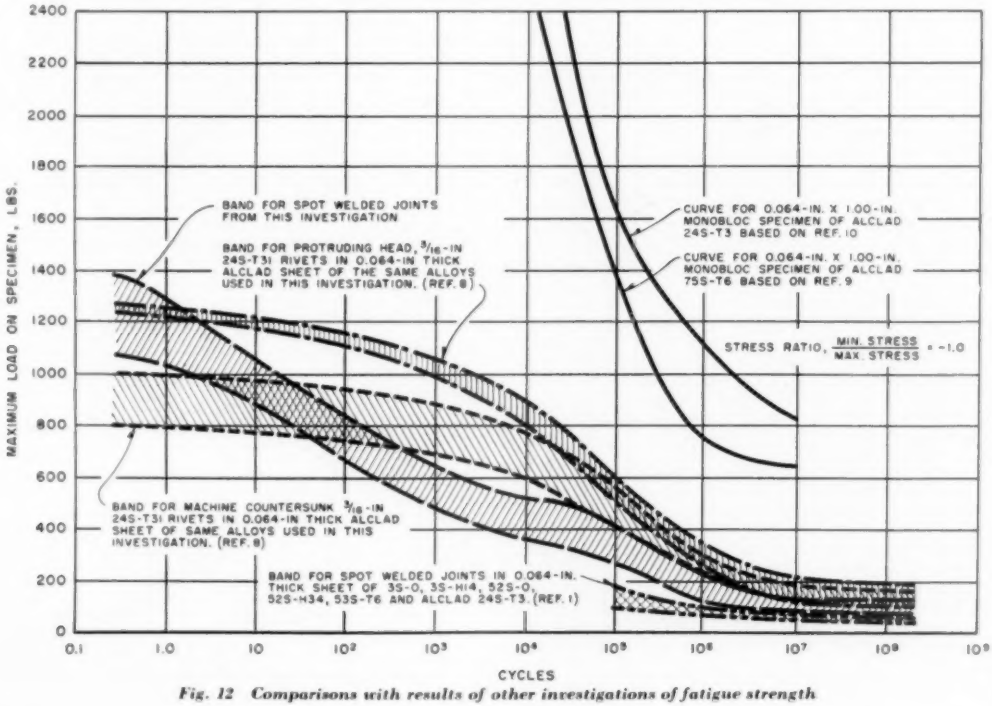
BAND FOR SPOT WELDED JOINTS FROM THIS INVESTIGATION
BAND FOR PROTRUDING HEAD, 3/16-IN 24S-T31 RIVETS IN 0.064-IN THICK ALCLAD SHEET OF THE SAME ALLOYS USED IN THIS INVESTIGATION. (REF. 8)
CURVE FOR 0.064-IN. X 1.00-IN. MONOBLOC SPECIMEN OF ALCLAD 24S-T3 BASED ON REF. 10
CURVE FOR 0.064-IN. X 1.00-IN. MONOBLOC SPECIMEN OF ALCLAD 75S-T6 BASED ON REF. 9
STRESS RATIO, MIN. STRESS / MAX. STRESS = -1.0
BAND FOR MACHINE COUNTERSUNK 3/16-IN 24S-T31 RIVETS IN 0.064-IN THICK ALCLAD SHEET OF SAME ALLOYS USED IN THIS INVESTIGATION. (REF. 8)
BAND FOR SPOT WELDED JOINTS IN 0.064-IN. THICK SHEET OF 3S-O, 3S-H14, 52S-O, 52S-H34, 53S-T6 AND ALCLAD 24S-T3. (REF. 1)
MAXIMUM LOAD ON SPECIMEN, LBS.
CYCLES

Fig. 12 Comparisons with results of other investigations of fatigue strength

RESULTS AND DISCUSSION

The test results are summarized in Figs. 6 to 12. It will be noted that there are a few data points which are outside the band shown in Fig. 6. All of these erratic points, some high and some low, were obtained from tests involving individual specimens from near the ends of the panels. Some of these spot welds were slightly noncircular when viewed on the exographs but otherwise appeared to be normal. Many of the spot welds showed cracks in the exographs taken before testing but the percentage of cracked spots was no higher in the group that gave high or low results than in the remainder of the test specimens. Careful examination failed to reveal any correlation between the appearance of the individual spot welds in the exographs and their performance in the fatigue test.

A study of the various S-N curves in relation to the over-all band (Figs. 7 to 11) shows clearly that the fatigue strengths of spot-welded joints are not greatly influenced by the alloy and temper of the sheet, especially for numbers of cycles exceeding about 1000. No one alloy was consistently best or worst in resistance to fatigue, although the good showing made by Alclad 24S-T3 at the higher numbers of cycles is worthy of note. Figures 8 and 9 show that artificial aging of the sheet after spot welding does not appear to have much influence on the fatigue strength.

The failures encountered in this investigation were approximately evenly divided between shear of the spot welds and fractures in the sheet adjacent to the spot weld. Nearly all of the failures at the lower numbers of cycles were in the spots while most of those at the higher numbers of cycles were in the sheet. The dividing line between the two types of failures came at numbers of cycles ranging from about 8000 to 80,000. It is probably significant that this range corresponds to the position of the "step" which seems to exist between the left- and right-hand portions of the S-N curves. More data would be needed to determine whether or not such a "step" is characteristic of fatigue curves on spot-welded joints.

Figure 12 provides a comparison of the results of this investigation with those of other investigations. It is evident that all types of joints are weaker than the parent material, as would be expected. Of more interest is the fact that the spot-welded joints are weaker in fatigue than either type of riveted joint investigated even though the static strengths of the spot-welded joints equal or exceed those of the riveted joints. The fact that the spot-welded joints in this investigation gave better fatigue strengths than those reported in Reference 1 can probably be attributed to improvements in the spot welds themselves brought about by advances in the art of spot welding.

CONCLUSIONS

The following conclusions are based on the data and discussion presented in this paper on the fatigue strength of joints in 0.064-in. thick Alclad aluminum alloy sheets with a single spot weld in each:

1. The S-N curves for all of the various sheet materials investigated lie within a rather narrow band. No one alloy or temper of sheet consistently gave the highest or the lowest fatigue strengths.
2. There was no correlation between static strength and fatigue strength of spot welds.
3. There was no evident correlation between the appearance of the spot welds in the exographs and the performance under fatigue loadings. While a few erratic test results were obtained, these did not seem to correlate with good or poor appearance in the exographs.
4. Nearly all the failures at low numbers of cycles in this investigation were by shear of the spot weld itself. At the higher numbers of cycles the predominant type of failure was a fracture in the sheet at the edge of the spot weld. The dividing line between the two types of failure came at numbers of cycles ranging from about 8000 to 80,000.
5. Artificial aging of aluminum alloy joints after spot welding produced no appreciable improvement in fatigue strength in this investigation.
6. The fatigue strengths of lap joints with single spot welds seem to be inferior to those of lap joints with single rivets having approximately the same static strength regardless of whether the rivets are of the protruding-head type or of the countersunk-head type.

Bibliography

1. Hartmann, E. C., and Stickley, G. W., "Summary of Results of Tests Made by Aluminum Research Laboratories of Spot-Welded Joints and Structural Elements," NACA Tech. Note 860, 1942; *Welding Research Supplement*, **XII** (4) 233–251 (1947).
2. Hess, W. F., Wyant, R. A., Winsor, F. J., and Cool, H. C., "An Investigation of the Fatigue Strength of Spot Welds in Aluminum Alloy Alclad 24S-T," *Ibid.*, **XI** (6) 344–345(1946).
3. McMaster, R. C., and Grover, H. J., "Radiography and the Fatigue Strength of Spot Welds in Aluminum Alloys," THE WELDING JOURNAL, **26** (3) 223–232 (1947).
4. Grover, H. J., and Jackson, L. R., "Fatigue Tests on Some Spot-Welded Joints in Aluminum Alloy Sheet Materials," *Ibid.*, **26** (4) 215–232 (1947).
5. McMaster, R. C., and Grover, H. J., "Spot Welded Aluminum Lap Joints Designed for Repeated Loads," *Product Eng.*, **XVII**, No. 11, 112–113 (November 1947).
6. McMaster, R. C., and Grover, H. J., "Spot-Welded Aluminum Components Designed for Repeated Loads," *Ibid.*, **XVII**, No. 12, 158–161 (December 1947).
7. Welter, Georges, "Fatigue Tests of Spot Welds—Improvement of Their Endurance Limit by Hydrostatic Pressure," *Welding Research Supplement*, **XIII** (6) 285–298 (1948).
8. Holt, Marshall, "Results of Shear Fatigue Tests of Joints with $^{1}/_{8}$-Inch Diameter 24S-T31 Rivets in 0.064-Inch Thick Alclad Sheet," NACA, Tech. Note 2012, February 1950.
9. Wallgren, G., "Fatigue Tests with Stress Cycles of Varying Amplitude," Flygtekniska Forsoksanstalten, FFA, Meddelande NR28, 1949.
10. Smith, F. C., Brueggeman, W. C., and Harwell, R. H., "Comparisons of Fatigue Strengths of Bare and Alclad 24S-T3 Aluminum Alloy Sheet Specimens Tested at 12 and 1000 Cycles Per Minute," NACA, Tech. Note 2231, December 1950.

Fracture Initiation and Propagation in Welded Ship Steels

An investigation and propagation of fractures in welded and prime plate indicates that the weld metal (E6010) electrodes cracked first

by P. J. Rieppel and C. B. Voldrich

Abstract

The initiation and propagation of fractures in welded and prime-plate Kinzel-type transversely notched bead-bend specimens were investigated. The steels used were Ship Steel Committee Project Steels "B_r" and "C" welded by E6010 electrodes. In all welded specimens, the weld metal cracked first and at very low bend angles. Prime-plate specimens cracked only after a much greater bend angle was reached. The difference in the amounts of energy absorbed by welded and prime-plate specimens was found to be chiefly in the difference in energy absorbed by the specimens prior to the initiation of cracks.

Results of this work and that of many previously reported investigations show that cracks are very likely to initiate in weld metal transverse to weld joints that are strained plastically in the longitudinal direction. Cracks from such origin may be the starting points of many structural failures.

Results suggest that the data from many welded test specimens be re-examined in light of data presented in this paper. It seems likely that poor performance, which has been believed to be caused by heat-affected zones, may in reality be directly related to weld-metal performance.

INTRODUCTION

FAILURES of welded steel ships, during and since World War II, have stimulated many investigations on quality of ship steels and the influence of welding upon the performance of large welded structures. Many specimens, both large and small, have been designed to study properties of prime ship plate and weld joints in these materials. These specimens have ranged in size from Charpy notched-bar specimens to full-scale sections of hatch corners of ships.

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Major objectives of the research program have been to: (*a*) determine the causes of brittle fractures of ships; (*b*) develop steels with optimum properties for welded ships; and (*c*) develop small test specimens and testing procedures which can be used to predict the performance of steels and weld joints when used in large welded structures.

Research was conducted at Battelle from July 1947 to December 1950 on the last of these broad objectives, for the Bureau of Ships, USN, under the sponsorship of the Committee on Ship Steel of the National Research Council. A study was made of various small mechanical test specimens to evaluate their usefulness for predicting the performance of steels and weld joints in large welded structures. Fundamental factors contributing to the results obtained with certain specimens were studied in detail.

In the early work at Battelle, a survey was made of published literature and unpublished information on the general subject. The test specimens described in the literature were appraised as to their relative merit for a study of strength, ductility and notch toughness of structural steels and welded joints in such steels. On the basis of this survey, four types of weld specimens were selected for further evaluation. Two hull-grade steels, Project Steels "B_r" and "C," which had been used in the full-scale hatch-corner tests, were used extensively in these tests.

Studies were made with the small test specimens, and with several modifications of those which appeared to be the most promising. Tests were made on the weld metals used in preparing the specimens. In these studies, series of specimens were tested over a range of temperatures to determine the temperature range in which transitions from ductile to brittle behavior occurred. The effects of preheat and postheat upon the performance of welded test specimens were also studied. The details of this work have been described in a previous paper, "Evaluation of Tests for Steels for Welded Structures," published in THE WELDING JOURNAL, April 1950. In brief, results obtained with the Kinzel-type notched-bend specimens showed a

Table 1—Mechanical Properties and Chemical Compositions of Project Steels "B_r" and "C"

Steel code letter	Type of steel	Steel condition	Mechanical properties*, † Yield strength psi.	Ultimate strength, psi.	Elongation In 2 in., %	Elongation In 8 in., %	Reduction in area, %	Hardness, rockwell B
B_r	Semikilled	As-rolled	32,200–34,600	55,600–58,600	46–42	35–33	71–58	58–63
C	Semikilled	As-rolled	34,500–37,600	61,500–68,500	43–35	32–28	63–50	66–69

Steel code letter	Chemical composition, %* C	Mn	Si	P	S	Cr	Ni	Mo	Cu	Al	Sn	N
B_r	0.18	0.73	0.07	0.008	0.030	0.03	0.05	0.006	0.07	0.015	0.012	0.005
C	0.24	0.43	0.05	0.012	0.026	0.03	0.02	0.005	0.03	0.016	0.003	0.009

* Boodberg, A., Davis, H. E., Parker, E. R., and Troxell, G. E., "Causes of Cleavage Fracture in Ship Plate—Tests of Wide Notched Plates," THE WELDING JOURNAL, **27** (4), Research Supplement, 186-s to 199-s (1948).

† The data for the mechanical properties are the lowest and highest values obtained for each steel.

somewhat better correlation with the results of full-scale hatch-corner tests than those obtained with the other test specimens studied. Both welded and unwelded Kinzel specimens showed that the "B_r" steel generally gave better performance than "C" steel. The Kinzel specimen also showed that welded specimens always gave poorer performances than prime-plate specimens. Preheat and postheat treatments generally improved the performance of welded specimens. For these reasons, a detailed study was made on fracture initiation and propagation in the Kinzel specimen to obtain basic information on its performance. This information was desired as background for interpreting and evaluating the results obtained with this and similar specimens.

The details of the fracture-initiation and propagation studies on the Kinzel specimens are described in this paper. Briefly, the results showed that fractures always developed in weld metal considerable in advance of their development in other areas. This early weld-metal failure dominated, or greatly controlled, the over-all performance of the test specimen. In other words, the weld-metal failure "triggered" the failure of the specimen.

FRACTURE-INITIATION AND PROPAGATION STUDIES ON KINZEL-TYPE SPECIMENS

The initiation and the propagation of fracture were studied in both welded and prime-plate specimens. The specimens were made of two steels, "B_r" and "C," which had been used extensively in previous research. The mechanical properties and chemical compositions of the steels are given in Table 1.

PREPARATION OF TEST SPECIMEN

The details of the Kinzel-type specimen are shown in Fig. 1. The coupons for the specimen were saw cut from the plates of "B_r" and "C" steels, and the surfaces were cleaned by grit blasting. The direction of rolling for all coupons was parallel to the longitudinal direction of the finished specimen.

For welded specimens, the weld beads were deposited on the coupons by automatic welding using the following schedule:

AWS electrode classification	E6010
Electrode diameter, in.	3/16
Amperes	175
Arc volts	27
Speed, in./min.	6
Arc time, sec.	40
Length of weld bead, in.	4
Heat input, joules/in.	44,750

All of the specimens were welded at room temperature and cooled in air. The aging time between welding and testing was eight days at room temperature. During the aging period, the final machining was done according to the sketch shown in Fig. 1. The sides of the

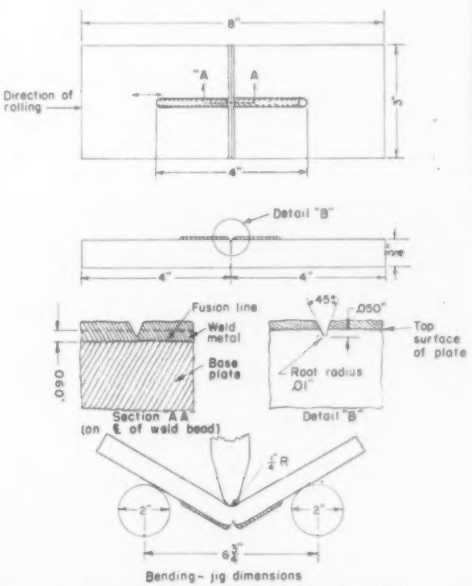

Fig. 1 Bend specimen with longitudinal weld bead and transverse notch (Kinzel design)

specimens were finished by grinding, and the notches were made with a fly cutter to accurately obtain the prescribed root radius.

Prime-plate specimens were machined to the same dimensions.

Selection of Testing Temperatures

Since the modes of fracture at temperatures well above and well below the transition temperatures of a given specimen are shear and cleavage, respectively, it was decided to look for differences in crack-initiation and propagation characteristics in the upper and lower parts of the transition-temperature range. It would have been desirable to make the tests at a range of temperatures, but the scope of the project limited the studies to the two conditions described above.

The transition-temperature ranges for Kinzel specimens of "B_r" and "C" steels were known from previous work. There was no problem in the selection of a test temperature in the upper part of the transition-temperature range for the test in which ductile behavior, with shear fracture, was desired. However, the selection of a test temperature for brittle fracture was more difficult. When the test temperature was much below the transition range, the specimens broke abruptly in the bending jig after very little deflection; this made it impossible to detect the onset and progress of the fracture. It was necessary, therefore, to use a test temperature at the lower end of the transition range, where the specimen steel retained some ductility, so that the initiation of cracking could be detected.

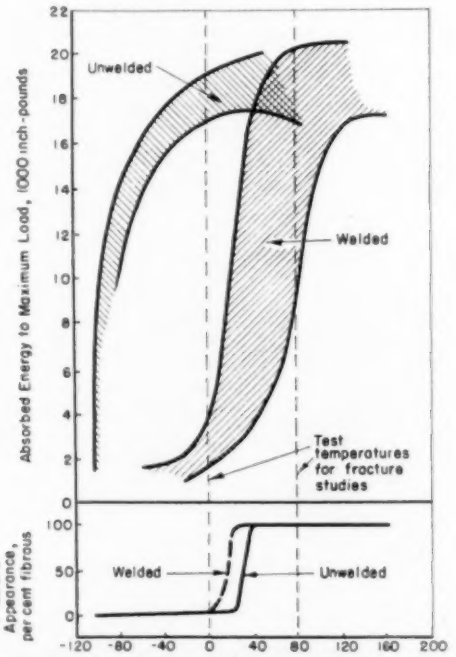

Fig. 2 Absorbed-energy and fracture-appearance curves for welded and prime-plate "B_r" steel Kinzel-type specimens, showing test temperatures used in fracture studies

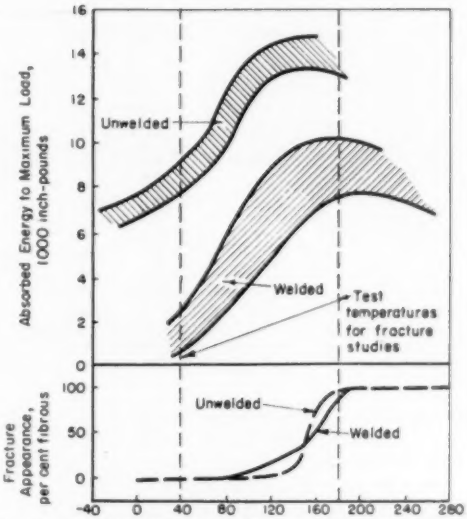

Fig. 3 Absorbed-energy and fracture-appearance curves for welded and prime plate "C" steel Kinzel-type specimens, showing test temperatures used in fracture studies

The test temperatures chosen for the "B_r" steel were zero and 80° F., for both welded and prime-plate specimens. In Fig. 2 are shown absorbed-energy and fracture-appearance curves for "B_r" steel, from data previously reported. The test temperatures are indicated by dotted lines. The 0° F. temperature is close to the transition range of welded specimens, but much above that of the prime-plate specimens. Had a temperature below the transition range of the prime-plate specimens been chosen, the welded specimens would have failed completely by cleavage and no fracture data could have been obtained. As a result, the data for unwelded "B_r" steel specimens were nearly identical for both test temperatures, these temperatures being in the ductile range for both cases.

For "C" steel, the test temperatures chosen were 40 and 180° F., for both welded and unwelded specimens. As shown in Fig. 3, the lower test temperature, 40° F., was at the bottom of the transition ranges of both the primeplate and welded specimens. In fact, some of the welded specimens failed by cleavage at this temperature. It was observed in this study that differences in crack initiation of specimens tested above and below the transition range are negligible. Temperature apparently had more influence on how cracks propagated in these specimens than on the time when cracking started.

Testing Procedure

Test specimens and bending jigs were immersed in a liquid medium at the test temperature for at least 5

min. before applying the load. Temperatures above the transition temperature were obtained by using water heated with resistance immersion coils. A mixture of methyl cyclohexane and dry ice was used when specimens were tested below the transition temperature.

All specimens were preloaded to 1000 lb. in an Amsler hydraulic-type testing machine. An Ames dial gage, located at the center of the specimens, was then set at zero to measure deflection during later loading. The preloading was used on all specimens to provide a uniform starting point. After preloading, the specimens were bent at a rate of approximately 0.075-in.-per-minute displacement of the platen.

Two or three specimens were bent at each of several deflections, ranging from 0.05 to 0.250 in. at midspan for welded specimens, and from 0.05 to 1.25 in. for prime-plate specimens. Following deformation, the specimens were sectioned transverse to the notch, as shown in Fig. 4. More sections were made in the welded specimens than in the prime-plate specimens.

The sections taken from the specimens were polished and examined for cracks. Where cracks were present, their depths were measured. In welded specimens, cracks were identified by the zone in the notch root in which they originated, that is, weld metal, heat-affected zone or base metal. In prime-plate specimens, cracks were identified by location, as center or edge sections. Average crack-depth data were tabulated and plotted against deflection.

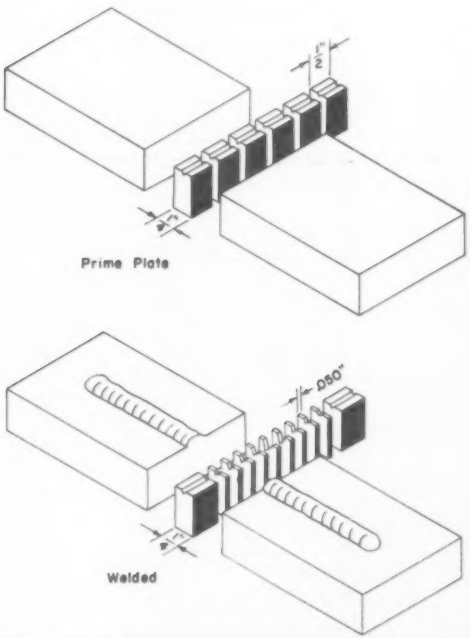

Fig. 4 Method of sectioning prime-plate and welded specimens, after bending to various deflections

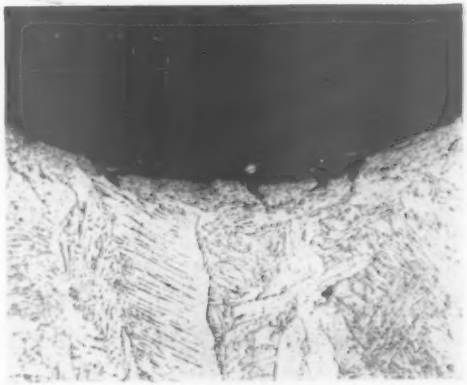

Fig. 5 Typical cracks appearing at root of notch in weld metal of a specimen, deflected 0.050 in. at the center

In prime-plate and welded specimens of both "B_e" and "C" steels, tested at the high and low temperatures, small cracks or surface tears were present in the root of the notch after 0.050-in. deflection at the center of the specimen. In both the prime-plate and welded specimens, these cracks occurred across the entire width of the specimen.

A typical example of these cracks or "surface tears" is shown in Fig. 5. As shown in this figure, several of these cracks were often found in the root of the notch of one cross section.

At 400 × magnification, some of the surface tears were quite wide, as shown in Fig. 6, and showed evidence that plastic deformation had taken place. Some cracks were sharp and comparatively deep, as those shown by Fig. 5. However, at the 0.050-in. deflection, there was usually some evidence of ductility and the cracks resembled tears, as shown by Fig. 6. As the specimens were deflected further, the cracks often opened up at the sides of the root radius, as shown by Fig. 7, instead of in the center, as might be expected.

In Figs. 5 and 6, there is evidence that a very thin

Fig. 6 Typical cracks or tears appearing in the heat-affected zone of a specimen deflected 0.050 in.

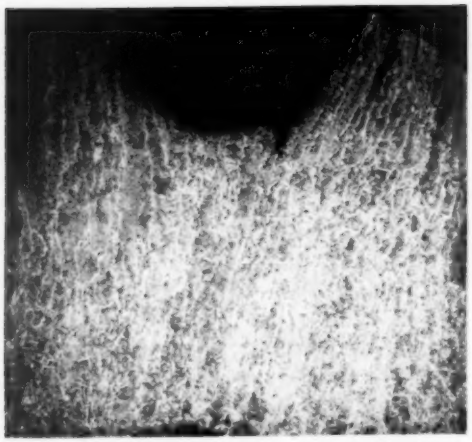

Fig. 7 Typical crack that has propagated with increase in deflection to 0.15 in.

surface layer of metal at the root of the notch was cold worked by machining. This cold working may have contributed to the early initiation of surface tears. To follow up this point, the notches of two specimens were lapped out to a depth below the work-hardened region and tested. Surface tears occurred at the root of the notch in the same manner as on the previously discussed specimens which were tested in the as-machined condition.

Since removal of the work-hardened layer appeared to have no particular advantage, and since this investigation was concerned with normal Kinzel-type specimens, the notches of the specimens were left in the as-machined condition.

In prime-plate specimens of "B_r" steel, all of which were tested above the transition temperature, there were only a few surface tears when specimens were deflected 0.050 in. The prime-plate specimens of "C" steel, which were tested at both high and low temperatures, contained surface tears after 0.050-in. deflection similar to those observed for "B_r" steel.

In welded "B_r" and "C" steels deflected 0.050 in., the surface tears were similar to those observed for prime-plate specimens, however, there were more surface tears in the welded specimens, especially in the weld metal and heat-affected zone of the weld. No significant difference was observed when comparing the number of cracks in welded specimens tested above and below the transition-temperature ranges for either series.

Crack Propagation

As the deflection at midspan of the Kinzel-type specimens was increased beyond 0.050 in., one of the several discontinuous cracks or surface tears that was present at 0.050-in. deflection increased in depth. An arbitrary depth of 0.005 in. was chosen to define a crack. The deflection at which cracks become 0.005 in. deep was measured as follows:

Deflection in Inches at Which Cracks Were 0.005 In. Deep

	"B_r" Steel		"C" Steel	
	80° F.	0° F.	180° F.	40° F.
Welded	0.15	0.15	0.10	0.06
Unwelded	0.77	0.82	0.52	0.55

A summary of the crack-depth data of both the prime-plate specimens and welded specimens is given in Fig. 8.

From these data, it was evident that cracks started to propagate beyond 0.005-in. depth in the welded specimens almost immediately, while the prime-plate specimens underwent considerable deformation before cracks propagated. It was noted that "C" steel specimens cracked at lower deflections than "B_r" steel, and that temperature differences appeared to have very little effect concerning when cracks started to propagate.

To demonstrate how cracks propagated, graphs were prepared as shown in Figs. 9 and 10 for welded and prime plate "C" steel tested at 180° F. These figures demonstrate the early fracture of the weld area of the welded specimens, as compared with the prime-plate specimens. They are typical of all of the curves obtained from welded and prime-plate "B_r" and "C" steels tested.

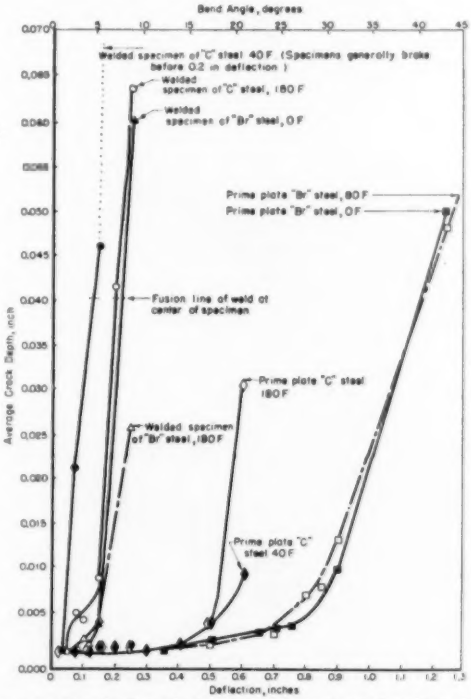
Bend Angle, degrees
Welded specimen of "C" steel 40 F (Specimens generally broke before 0.2 in deflection)
Welded specimen of "C" steel, 180 F
Welded specimen of "Br" steel, 0 F
Prime plate "Br" steel, 80 F
Prime plate "Br" steel, 0 F
Fusion line of weld at center of specimen
Prime plate "C" steel 180 F
Welded specimen of "Br" steel, 180 F
Prime plate "C" steel 40 F
Average Crack Depth, inch
Deflection, inches

Fig. 8 Depth of cracks in welded and prime-plate Kinzel-type specimens of "B_r" and "C" steel tested at various temperatures, and various deflections at mid-span

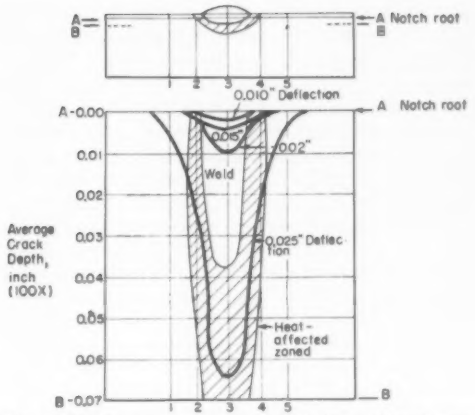

Fig. 9 Crack propagation in welded "C" steel Kinzel-type specimens tested at 180° F. (also see Fig. 13)

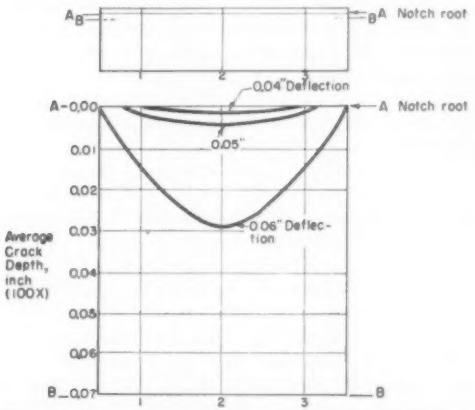

Fig. 10 Crack propagation in prime-plate "C" steel Kinzel-type specimens tested at 180° F.

A typical crack in a welded specimen is shown by Fig. 11. A typical pattern by which cracks propagated in welded specimens is shown in Fig. 12. The step-like pattern appearing on the fractured surface represents progressive steps in the propagation of the crack as the specimen was bent. The crack-pattern lines were deepest under the welds for the early stages of the cracking and decreased in depth on either side of the weld through the heat-affected zone and unaffected base metal.

Crack Propagation and Energy Absorption

The crack-propagation data explain the inferiority of welded Kinzel-type specimens compared with prime-plate specimens of the same design. In the early studies with these specimens, energy-absorbed versus temperature curves were used to study transition ranges. The energy-absorption data for these curves were obtained originally by determining the area under load-deflection curves for the test specimens. When the deflection at which cracking started was determined, it was then possible to determine: (*a*) energy absorbed by the specimen before cracking and (*b*) energy absorbed after cracking.

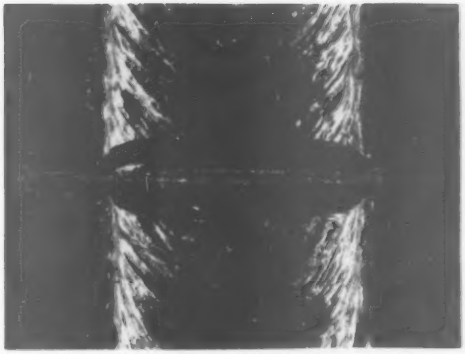

Fig. 11 Fracture in a welded "C" steel Kinzel-type specimen tested at 190° F., and deflected 0.200 in.

In Fig. 13, energy absorbed to maximum load of Kinzel-type specimens of "B_t" and "C" steels is shown. This energy is divided into energy absorbed before and after cracking.

Figure 14 compares the energies absorbed by the specimen after cracking. There is a large difference in energies absorbed prior to cracking of the welded and prime-plate specimens. There is much less difference in energies absorbed by the same specimens after the start of cracking. Therefore, it appears that early cracking in welded specimens was responsible for the low energy values for welded Kinzel-type specimens, as compared with prime-plate specimens tested at the same temperature.

In cases in which preheating and postheating have been found to improve the performance of welded

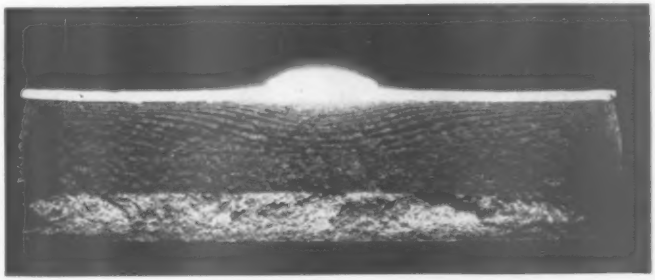

Fig. 12 Pattern of fracture propagation in a welded Kinzel-type specimen

Kinzel-type specimens,[1] this improvement probably resulted directly from improvements in weld metal and the heat-affected zones of welds. The improvement in weld metal presumably allowed more deformation before cracks started, and thus better performance was obtained at lower temperatures than with specimens which did not have the benefit of preheat or postheat treatments.

GENERAL DISCUSSION

In view of the findings presented in this paper, a discussion of some of the accumulated information from various investigations in this field is in order. Some questions are asked and suggestions are made to stimulate discussion on the part that weld metals play in initiating fractures in weldments, and again to focus attention on the significance of the heat-affected zone in the performance of weld joints in ship-grade steels.

Performance of Welds Versus Direction of Strain

The data presented in this paper show that, in the notched weld-bead type of specimen tested, the bending fracture initiated and propagated first in the weld metal. It appears that weld metal was the "weak link," and had less ability to deform than the heat-affected zone and the unaffected base material. This is at variance with some of the generally accepted ideas on the characteristics of weld metal and the performance of welded joints.

The results of many investigations have shown that weld metals are quite ductile and reasonably notch tough even at low temperatures, when tested by standard methods. It has also been shown repeatedly that heat-affected zones of welds may contain areas of low ductility and low notch toughness. Thousands of specimens have been taken transverse to weld joints and tested in tension and bending in welder qualification tests and in various investigations. In these tests, it is almost always shown that sound weld metal has satisfactory strength and good ductility. Such specimens have been bent through 180 degrees without failures in weld metal or heat-affected zones. When failure does occur in such tests, it usually starts in defective areas of weld metal.

In the Kinzel-type specimen, the weld metal at the root of the notch was strained in a direction parallel to the longitudinal direction of the weld. This weld metal was required to deform along with heat-affected base metal and unaffected base metal. Under these conditions, the weld metal was first to fail as strain was increased. Its failure "triggered" the failure of the specimen.

There are several very good examples in the literature of similar performance of weld joints in test specimens. A majority of such specimens have contained no transverse machined notches in the weld as was present in the Kinzel specimen. In large welded tubular specimens tested at the University of California,[2, 3] multipass butt welds in $^3/_4$-in.-tube walls were subjected to 2:1 and 1:1 biaxial stress conditions. As plastic strain developed in the specimens, the weld joints necessarily elongated along with the base material. The failures started in the weld joints in a majority of the cases. The cracks developed transverse to the

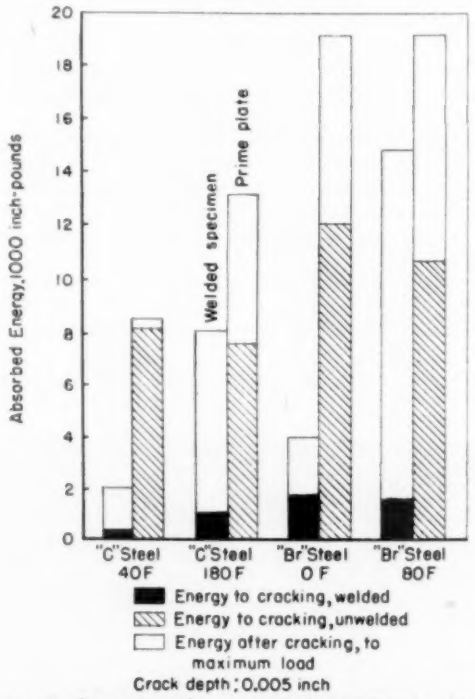

Fig. 13 Comparison of energy to cracking and energy after cracking absorbed by welded and prime-plate Kinzel-type specimens of "B," and "C" steels

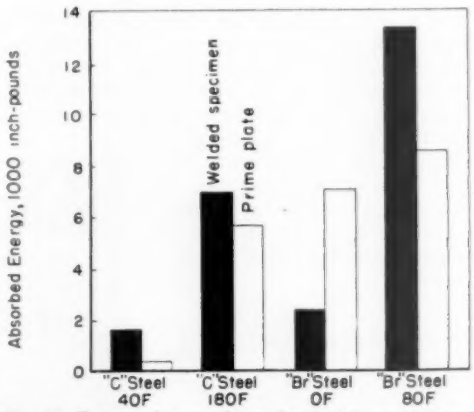

Fig. 14 Energy after cracking absorbed by welded and prime-plate Kinzel-type specimens of "B," and "C" steels

welds. It was not definitely proved that the weld metal failed first, but it was definite that the fracture usually initiated in the weld joint. Similar tests on large flat-plate bend[4] specimens with longitudinal butt welds on the center line of the specimens gave similar performance. Failures in spherical specimens[5] initiated from transverse cracks in butt welds that occurred during pressure testing. Heavy, longitudinally welded plate specimens simulating deck and hull joints which were studied by Bibber[6] failed first in the welds when tested in tension.

In most of these cases, especially when no machined transverse notches were present, there was considerable elongation before failure, but when failure started it usually initiated in the weld joint. In some investigations,[2,5] failures were proved to have initiated in defects in weld metals and in a few cases in sound weld metals. However, in most cases it was definite only that failure initiated in the weld joint, but it was not clear whether it initiated in weld metal or heat-affected base metal of the joint.

There is ample evidence that weld joints are more than likely to be the source of initial cracks when weldments are deformed in a direction parallel to weld joints. The explanation of this deficiency probably involves metallurgical properties of weld metal and heat-affected zones. It has been shown repeatedly that preheat and postheat treatments of weld joints greatly improve their performance in this respect.

In light of this discussion, if in the "shake down" or in service of a large welded structure, it is required that a very short gage length of restrained weld metal in a joint deform plastically in the longitudinal direction to relieve a local stress concentration, it is quite possible that cracks may be initiated in the weld metal during such adjustments.

Welded Specimens Versus Prime-Plate Specimens

In several investigations, many small welded specimens have been tested by bending or by static tension. Prime-plate specimens of the same dimensions as the welded specimens have usually been tested also. Comparisons of results from the two sets of specimens have been made to show the influence of the welding upon the performance of the material. Almost invariably, results from series of specimens of this type tested over a range of temperatures have shown inferior performance of the welded specimens. In some cases, for certain structural steels, it has been found that the difference in performance between welded and prime-plate specimens is very great; while in other steels of the same grade, the difference is much less. It is, therefore, reasoned that welding does more damage to one steel than another of the same general type, and that one steel is more desirable for welded structures than the other. Much work has been done to develop tests and methods of measuring the influence of welding on structural steels and to determine the extent to which welding impairs the serviceability of structural steels in large structures. So far, no good method has been developed.

In view of data presented in this paper, it seems important to re-evaluate results obtained from many small welded specimens. When a small welded specimen of structural-grade steel (carbon under about 0.25%), such as the Kinzel specimen, is bent, it appears more than likely that the weld metal will fail first at a very low bend angle. When the weld cracks, this immediately subjects the rest of the specimen to a very sharp notch which is quite different from the original geometry of the specimen. Regardless of the quality or "weldability" of the steel being tested, it appears that this early crack in the weld metal "triggers off" the failure of the specimen. Once this crack occurs, then the remainder of the cross section of the specimen (usually 95% or more) is subjected to entirely different test conditions, in the form of notch geometry, than at the start of the test. Under the influence of this drastically modified notch geometry, two steels may perform entirely differently, even though they give similar results under the influence of a normal machined notch. Thus, it may be erroneously concluded that one steel was influenced more by welding than the other, when in reality one steel is more notch sensitive than the other when subjected to the notch geometry of a crack started in weld metal.

It has been shown by some investigations that in some structural-grade steels, cracks start first in heat-affected metal or notched-bend specimens.[7] If it were true that cracks always start first in heat-affected zones and that the heat-affected zone of one steel has greater resistance to the initiation of cracks than that of another, then it could be shown that one steel is truly influenced more by welding than another. Also, if it could be shown that the heat-affected zone of one steel affords more resistance than another to the propagation of a crack started in the weld metal, then it could truly be shown that one steel is affected more or less by welding than another similar steel. Test results of this kind which involved the heat-affected zone as an important factor in the performance of the weldment could be said to bear on the "weldability" of the steel, as the authors understand that term.

Much remains to be determined in this field. Much more work needs to be done to closely analyze the performance of such specimens to understand their true behavior and interpret results obtained.

In recent literature, several series of explosion tests on welded and prime-plate specimens of steel have been reported.[8–10] In this test, a weld joint is strained in the longitudinal direction while it may or may not be strained materially in the transverse direction depending upon the strength of the weld metal and heat-affected zone. These specimens are subjected initially to biaxial stresses of about equal magnitude as shown by the deformation of the prime plates. An area under the charge is reported, in one test,[8] to be subjected to triaxial stresses. Great difference in energy absorption has been shown between prime-plate and welded

specimens. Also, important differences have been shown between specimens welded with various types of weld metals and welding techniques. After an examination of pictures of broken specimens shown in literature, it is believed that the fractures in many of these specimens are "triggered" by cracks which open in weld metal as it is strained in the longitudinal direction. If this is true, and it appears likely, the performance of these test specimens is dominated by the performance of the weld metal. The performance of the steels in these studies is influenced by the sharp crack originating in the weld metal It seems then that this test is in reality very likely to be predominantly a test of weld metal. It may in reality provide little information about the heat-affected zone of welds. It seems highly desirable that a detailed study of the initiation of fractures in such specimens be made in order to evaluate properly results obtained from the tests.

What appear to be differences in the influence of welding on various steels within a certain class may vanish completely or take on new significance when the details of the true performance of test specimens is determined.

The results of work reported in this paper suggest that attempts should be made to differentiate between the energy absorbed by any test specimen up to the point of initial fracture, and the energy absorbed during propagation of fracture. The differences in energy required to start fracture may prove to be much more important to the evaluation of steels, weld metal and weld joints than the energy required to propagate a fracture after it is once started.

Weld-Joint Properties and Initiation of Fractures in Ships

Much information has been accumulated on the properties of the principal areas of weld joints in ship-grade steels when tested under various conditions by laboratory specimens. More than adequate strengths have been developed in weld metals, and reasonable ductility and notch toughness is obtained if the welds are deposited by certain rigid techniques and procedures in certain size welds. Heat-affected zones of welds in ship-grade steels have also been shown to have adequate properties when the welds are properly made and the specimens are tested by conventional methods. This information shows in general that weld joints have quite acceptable properties, and the satisfactory performance of thousands of weldments have proved the value of welded joints.

On the other hand, laboratory test results, such as those described in this paper, and studies conducted by many other investigators show that weld joints are deficient in at least some respects. The weld metal is subject to defects such as porosity, hot cracks, cold cracks, microfissures, fisheyes, notch sensitivity and low ductility. These defects may be present even when good workmanship is used in producing the weld. It has been shown repeatedly that heat-affected zones may contain areas of high hardness, low ductility and low notch properties. Also, it has been reported that the heat-affected zones of welds in some steels have much poorer properties than the heat-affected zones of welds in other steels of the same class, even though causes for these differences are generally unknown. In general, the properties of the principal regions of weld joints may be far from what is ideally desired.

The engineer is confronted with laboratory information on weld joints on the one hand and service performance of welded structures on the other. There are thousands of weldments giving satisfactory service, which indicates that weld joints are predominantly adequate. On the other hand, there have been many major failures of welded structures and a great many more minor failures which indicate that deficiencies shown by laboratory tests may have an important influence upon service performance. Unfortunately, there is too little direct correlation between service failures and laboratory test results.

Thousands of cracks have been reported in weldments during service. In very few cases, however, have detailed studies been made to determine if the fractures initiated in weld joints, and particularly what part of the weld joint was responsible for the initial cracks. The origin of a great many failures has been traced directly to serious defects in weld joints caused by poor workmanship. Information of this kind is useful to production and quality-control people, but is of little value to the metallurgist and welding engineer. There are almost no records in the literature of failures initiating in sound, properly made welds of adequate size to carry the loads which may be placed on them in service. Little information of this kind has come out of the investigations and records on service fractures in welded ships.

In reports on full-scale hatch corners tested at the University of California,[11–16] it was recorded that fractures of the standard hatch-corner specimens initiated in welds between the deck plate, doubler and the hatch combing. This, at first, may appear to indicate that poor ductility, low notch strength or some such deficiency of the weld metal or heat-affected zone of the welds was responsible for the location of the initial fracture. However, a close examination of the design of the weld joints shows that the fillet welds at this location were not large enough to produce a 100% efficient joint between the parts that were joined. The weld joint in reality was designed to be only a 60 to 80% efficient joint. Therefore, as the structure took load in this area, which also contained a severe stress concentration, the fillet welds failed because they were not large enough to be equal in strength to the parts which they joined. These tests, while they were valuable in many other ways, showed particularly that an undersized fillet weld is not so strong as the parts that it joins. This raises a very important question. How often in service have weld failures resulted from fillet welds simply being too small to produce 100% joints? Summarizing, it is difficult to say what the straight

hatch-corner tests did tell of the various steels or of their weldability.

In two hatch-corner specimens of modified design, full-penetration welds were used in the location mentioned above. These specimens absorbed much more energy than standard specimens, and the failure, as shown by the pictures, appeared to initiate in base material instead of in weld metal. These failures may have initiated in heat-affected material with deficient properties, but such information was not reported.

Other large weldments that have been tested are large box girders and sections of ships. Reports on these studies contain almost no information regarding the exact location at which the fracture initiated. There are still some very important questions about the failure of such specimens. First, did failure initiate in sound, adequate weld joints? If so, did the fracture initiate in weld metal or in heat-affected metal?

It is obviously very difficult to obtain information in many cases regarding the exact location of initial fractures in a broken structure. This is the obvious reason for the lack of such information. However, it seems of paramount importance that every effort should be made to obtain it.

It seems that too much emphasis cannot be placed on this point. Along with the present knowledge of deficiencies of certain areas of weld joints, as shown by laboratory specimens, it is also definitely known that in a welded structure certain areas of the weld joint do not behave as might be indicated by the properties of an area when tested by small specimens. In other words, the joint may perform entirely differently than might be expected from studies of its individual parts. For this reason, the real deficiencies of the weld joint can be determined only by careful analysis of failures, to determine the "weak link" that causes the failure in actual structures. Some may say that this has been done. Another may say that it is not possible. However, the view taken here is that there is too little of this type of information available at present, and it can be accumulated if the right type of organized effort is devoted to the problem.

There is almost no information to show that a minor or major failure in service has initiated in a sound, properly made weld of adequate size. Therefore, little is known about the part that weld metal as such or heat-affected zones as such have played in producing service failures. Properties of these parts of weld joints as determined by various studies indicate that these elements of weld joints are often deficient in properties, but there is very little direct evidence that these deficiencies have initiated many failures.

CONCLUDING STATEMENTS

The investigation of the initiation and propagation of cracks in Kinzel-type specimens of "B_r" and "C" steels showed that fractures in these welded specimens initiated and propagated first in weld metal. The behavior of the welded specimens was controlled primarily by the cracking of the weld metal at a very low bend angle as the specimens were tested. It was concluded that the Kinzel-type specimen failed to show definite differences in the influence of the heat of welding upon the performance of the two steels studied.

The results of this investigation suggest that: (*a*) more attention should be given to the properties of weld metals and efforts made to improve them; (*b*) the value of data obtained from many welded bend-test specimens for evaluating the weldability of steels is questionable; and (*c*) much more work should be done to determine the precise origin of fractures in welded structures.

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Bibliography

1. Rieppel, P. J., Kline, R. G., and Voldrich, C. R., "Evaluation of Tests for Steels for Welded Structures," THE WELDING JOURNAL, **29** (4), Research Suppl., 195-s to 212-s (1950).

2. Davis, H. E., Troxell, G. E., Parker, E. R., and O'Brien, M. P., "Behavior of Steel Under Conditions of Multiaxial Stresses and Effect of Welding and Temperature on This Behavior (NS-306): Tests of Large Tubular Specimens Ship Plate Series," Final Report OSRD 6365, Serial No. M-542.

3. Troxell, G. E., Parker, E. R., Davis, H. E., and Boodberg, A., "The Effect of Temperature and Welding Conditions on the Strength of Large Welded Tubes," THE WELDING JOURNAL, **27** (1), Research Suppl., 34-s to 49-s (1948).

4. Davis, H. E., Troxell, G. E., Parker, E. R., and Boodberg, A., "Investigations of Brittle Cleavage Fracture of Welded Flat Plate by Means of a Bend Test," Technical Report Serial No. SSC-6.

5. Walmsley, J. L., "Spherical Shells Subjected to Internal Pressure and Low Temperature," THE WELDING JOURNAL, **30** (3), Research Suppl., 153-s to 167-s (1951).

6. Bibber, L. C., "A Study of the Tensile Properties of Heavy Longitudinally Welded Plate Specimens Simulating Deck and Shell Joints," *Ibid.*, **24** (4), Research Suppl., 193-s to 225-s (1945).

7. Stout, R. D., and McGeady, L. J., "Metallurgical Factors in the Embrittlement of Welded Plate," *Ibid.*, **26** (9), Research Suppl., 683-s to 692-s (1947).

8. Mikhalapov, G. S., "Direct Explosion Tests of Welded Joints," *Ibid.*, **29** (3), Research Suppl., 109-s to 122-s (1950).

9. Mikhalapov, G. S., "Evaluation of Welded Ship Plate by Explosion Testing," *Ibid.*, **30** (4), Research Suppl., 195-s to 201-s (1951).

10. Hartbower, C. E., and Pellini, W. S., "Explosion Bulge Test Studies of the Deformation of Weldments," *Ibid.*, **30** (6), Research Suppl., 307-s to 320-s (1951).

11. De Garmo, E. P., Miriam, J. L., Grassi, R. C., and O'Brien, M. P., "Cleavage Fracture of Ship Plate as Influenced by Design and Metallurgical Factors (NS-336): Hatch Corner Specimen Tests," Progress Report OSRD 5352 (M-512), July 21, 1945.

12. De Garmo, E. P., Miriam, J. L., Grassi, R. C., and O'Brien, M. P., "Cleavage Fracture of Ship Plate as Influenced by Design and Metallurgical Factors (NS-336): Part I—Hatch Corner Specimen Tests," Final Report OSRD No. 6387 (M-607), Dec. 4, 1945.

13. De Garmo, E. P., Miriam, J. L., Grassi, R. C., Harman, J. W., and O'Brien, M. P., "Cleavage Fracture of Ship Plate Hatch Corner Tests," Progress Report SSC-1.

14. De Garmo, E. P., Miriam, J. L., and O'Brien, M. P., "Causes of Cleavage Fracture in Ship Plate: Hatch Corner Tests," Final Report SSC-5, Oct. 23, 1946.

15. De Garmo, E. P., and Boodberg, A., "Causes of Cleavage Fracture in Ship Plate: Hatch Corner Design Tests," Final Report SSC-16, Dec. 4, 1947.

16. De Garmo, E. P., "Tests of Various Designs of Welded Hatch Corners for Ships," THE WELDING JOURNAL, **27** (2), Research Suppl., 50-s to 68-s (1948).

Discussion by W. H. Wooding

The authors are to be congratulated for the valuable contribution they have made to the study of fracture initiation and propagation in welded test specimens of ship steels. The conclusions drawn are in substantial agreement with other investigations which have indicated that weld metal deposited with Type E6010 electrodes is susceptible to fissuring or cracking when subjected to a limited amount of strain.

One investigation concerned with the susceptibility of weld metals to fissure or crack under limited strain used the test procedure shown in Fig. 1. This procedure, referred to as "The Mathias Weld Metal Fissuring Test" since it follows the suggestions of D. L. Mathias of Arcrods Corp., Sparrows Point, Md., utilizes a restrained single-Vee butt joint which is welded under selected conditions. Transverse weld specimens cut from the assembly are prepared as shown and loaded in tension to develop a predetermined amount of strain across the weld deposit. After release of the load, the specimens are examined without further preparation.

Representative samples showing the results of test of several assemblies welded with Type E6010 electrodes at several preheat and interpass temperatures are shown in Fig. 2. The assemblies were prepared using $^3/_{16}$-in. diameter electrodes at the preheat and interpass temperatures of 0, 100, and 300° F. A welding current of 190 amp. at 26 arc volts (d. c.—reverse polarity) and a full weave technique were used to deposit all welds. When completed, transverse weld specimens were taken from the assemblies and prepared for test as shown in Fig. 1. These were subjected to a tensile load to develop $7^1/_2$% strain in 2 in. across the weld. Upon reaching that strain level, the load was released and the prepared surfaces of the specimens were examined. Representative specimens were selected and photographed.

Referring to Fig. 2, the specimen representing the assembly prepared at a preheat and interpass temperature of 0° F. shows that a considerable number of fissures on the prepared surface of the weld deposit developed as a result of the strain imposed. The specimen representing the assembly prepared at a preheat and interpass temperature of 100° F. fails to show much improvement in so far as a reduction in the number and magnitude of the fissures are concerned. However, the specimen representing the assembly prepared at a preheat and interpass temperature of 300° F. shows a decided reduction in the amount of fissuring on the surface of the weld metal. It is interesting to note the similarity of the directional orientation of the fissures occuring in the 0 and 100° F. specimens while those occurring in the 300° F. specimen lack this similarity in direction.

These results appear to substantiate the findings of the authors in that the use of preheat does improve the performance of weld metal deposited with Type E6010 electrodes. Such weld metal, upon being strained, has a lesser tendency to fissure when compared with welds deposited without preheat or at subnormal temperatures.

The factor influencing the development of fissures in welds deposited with Type E6010 electrodes is not clearly revealed by the results illustrated in Fig. 2. To better illustrate a probable cause for such fissuring,

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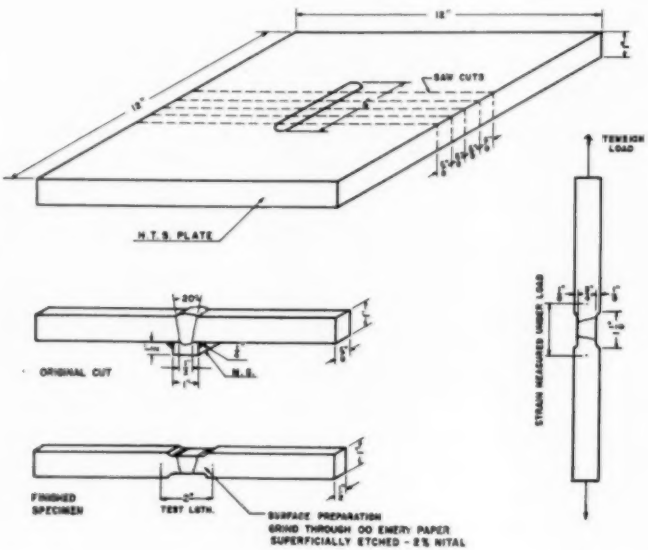

Fig. 1 Mathias weld metal fissuring test

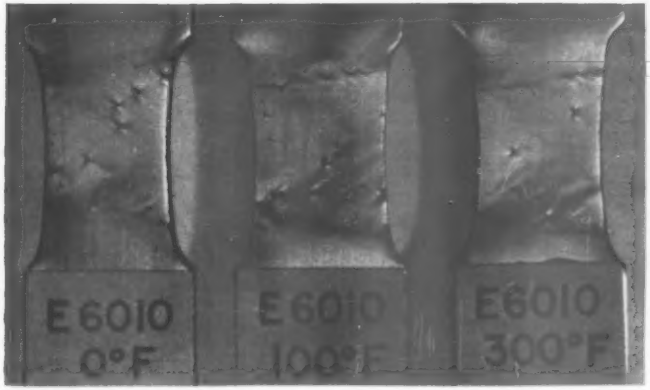

Fig. 2 Representative specimens welded with 5/16-in. diameter type E6010 electrodes, 7.5% strain in 2 in. across weld

Fig. 3 shows representative specimens taken from two assemblies welded with low hydrogen Type E7016 electrodes. In each case, 5/16-in. diameter electrodes were used and the welds were deposited with a welding current of 200 amp. at 22 arc volts at a preheat and interpass temperature of 0° F. One assembly was welded with electrodes, the coating of which had an average moisture content of 1.70%, while the moisture content of the coating of the electrodes used to weld the second assembly averaged 0.42%.* Specimens taken from the assemblies were prepared and strained to 7½% in 2 in. in the same manner as those shown in Fig. 2. As shown in Fig. 3, the specimen representing the assembly welded with the electrode of high moisture content shows evidence of fissuring on the surface of the weld deposit. However, the specimen representing the assembly deposited with the low moisture content electrode does not show any evidence of fissuring on the weld surface.

The same specimens were further strained to 12.5% in 2 in. across the weld and are shown in the photograph, Fig. 4. As would be expected, the fissures on the surface of the weld deposited with the high-moisture content electrode have increased in size. However, the weld deposited with the low-moisture content electrode still shows no evidence of fissuring.

It has been established by an extensive number of tests of this type that fissuring in low-hydrogen type weld deposits is directly associated with the moisture content of the electrode coating. As the moisture content of the coating is reduced the tendency of the weld metal to fissure under strain likewise is reduced. This would indicate that fissuring may be a function of the quantity of hydrogen present in the arc atmosphere

* Determined at 2400° F

Fig. 3 Representative specimens welded with 5/16-in. diameter type E7016 electrodes, 7.5% strain in 2 in. across weld

Fig. 4 Representative specimens welded with 5/16-in. diameter type E7016 electrodes, 12.5% strain in 2 in. across weld

and absorbed by the weld metal. Since the arc atmosphere generated by Type E6010 electrodes contains considerable quantities of hydrogen (as compared to that of low-hydrogen type electrodes) it would appear that the fissuring resulting from the limited strain of such deposits is associated with the absorption of hydrogen by the weld metal.

Therefore, it is suggested that where bead weld bend tests are used in the evaluation of the performance of welded ferritic materials consideration be given to limiting the hydrogen content of the weld deposits. This could be accomplished by the use of suitable low-hydrogen type electrodes with the moisture content of the coatings controlled to some predetermined level.

Authors' Reply

The authors extend their appreciation to W. H. Wooding for his discussion and the interesting and pertinent data on weld-metal properties which he has added to this discussion.

In view of these data, it seems in order, as Mr. Wooding suggested, that low-hydrogen electrodes (with controlled moisture) be considered for use on bead-weld bend tests similar to the Kinzel tests. It is expected that E7016 weld metal would probably bend more than E6010 weld metal before fracture starts in a Kinzel-type specimen. It might be capable of deforming enough so that the initial fracture would start in the heat-affected zone of the specimens. It seems important that a study of this kind should be made.

Recent work conducted by Dr. W. S. Pellini and associates at the Naval Research Laboratory with explosion bulge specimens has shown very definitely that weld metals deposited by low-hydrogen electrodes are superior to those made by conventional E6010 electrodes.

If it were possible to find a weld metal that was always capable of deforming enough without fracturing so that failures would always initiate in heat-affected zones, then it would be much easier to study the influence of welding upon base materials.

At this point, it seems important to again make clear that all testing described in this paper, and most of the research referred to in the general discussion, concerned welds made in ship steels with high-hydrogen types of electrodes.

Discussion by W. S. Pellini

There can be no doubt that the detailed studies of crack initiation in Kinzel-type specimens reported by the authors have yielded information of considerable consequence. As is often the case, critical investigations of a basic nature provide the key which is required to resolve conflicting data obtained by purely empirical approaches. The generally accepted premise that "weldability" tests evaluate the response of the steel (presumably the heat-affected zone) to the heat of welding stands in need of considerable revision in the light of the controlling effect of the weld metal shown by the investigation.

It is significant that the controlling effect of the weld metal observed for bead-on-plate welds has been shown also for full-size practical welds. Recent investigations[1] at the Naval Research Laboratory with Explosion Bulge specimens have shown that weldments of structural steel likewise fail by crack initiation in the welds. It was also shown that the performance of the weldments is directly related to the notch toughness of the welds.

It should be recognized that these two separate investigations featured testing procedures which are not in any way discriminating to the weld area. Danger spots in structures generally feature welds at positions of highest stress concentration—thus, the importance of the weld must be considered to have been evaluated in conservative fashion. Accordingly, no exception can be taken to the conclusion that efforts should be made to improve weld metal properties. The case which is presented against the weld metal, however, does not in any way absolve the base steel. This fact certainly is implied in the paper but not specifically stated—a clear statement in this respect is needed so that there will be no misunderstanding that structural failures are simply attributable to welds with consequent minimization of the importance of the steel. Catastrophic failures entailing brittle fracture through the base steel present in themselves the most evident possible proof of steel inadequacy. There are two apparently separate functions to be performed by the weld and steel elements—it is a function of the weld to be as resistant as possible to crack initiation and that of the steel to be as resistant as possible to crack propagation. The plate function must be accomplished regardless of weld quality for adventitious flaws such as arc strikes may initiate the travel of brittle cracks at other than weld positions. It must be concluded that the elimination of structural failures is dependent on the improvement of both weld and steel elements of weldments.

The authors indicate that Kinzel-type specimens may be used to study differences in properties of weld metals but not to evaluate the weldability of steels. That this is so in the sense that weldability signifies reaction to the welding heat by the base steel is quite evident—the significant fact being that the HAZ is not the critical element which determines the performance of the specimen. This is also so in the less

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[1] Hartbower, C. E., and Pellini, W. S., "Investigation of Factors Which Determine the Performance of Weldments," THE WELDING JOURNAL, 30 (10), Research Suppl., 499-s to 511-s (1951).

Note: The opinions expressed herein are those of the writer and do not necessarily represent the opinions of the Navy Dept.

evident sense of weldability which entails the over-all performance of the specimen in transition from ductile to brittle behavior.

The case of crack initiation in one element of the Kinzel specimen (the weld) with consequent propagation in an element of different metallurgical and mechanical properties (the steel) makes transition test results extremely difficult to interpret. This is evident from a consideration of the effect of a tough, crack-resistant weld as compared to a poorer weld when tested on the same steel in a Kinzel-type specimen. The lower test temperature required to start cracking in the tougher weld will also affect crack propagation in the steel. Thus, the use of temperature to affect the initiation of cracking in one element becomes confused with the simultaneous effect of temperature on crack propagation in the other element. Obviously, the crack initiation features of the critical element must be dissociated from the crack propagation features which may occur in an element of completely different metallurgical and mechanical properties. These two features should be recognized as independent variables and evaluated accordingly.

It should also be recognized that notched, longitudinal, bead-on-plate weldability specimens represent a highly specific condition of loading; i.e., loading in a longitudinal weld direction. Caution should therefore be used in interpretations which are expected to have general applicability to service. Inasmuch as the deformation features of welds in transverse loading are considerably different from those developed in longitudinal loading[1] it is entirely possible that in borderline cases the critical crack starting element may be changed by changing the load direction. As a simple illustration it may be visualized that the HAZ at the toe of a weld featuring reinforcement is in an unfavorable stress condition conducive to failure when loading is transverse to the weld. This same position is not at disadvantage when loading is along the weld direction.

Authors' Reply

The authors wish to thank Mr. Pellini for his informative discussion. It is strongly recommended that the readers of this article read in detail the reference given at the end of Mr. Pellini's discussion.

We agree that a definite statement should be made to the effect that the data and discussion presented on weld metal does not in any respect absolve the base steel in welded structures. It is emphasized in our article that improvements are needed in weld metals. Likewise, improvements in steels for ship construction are needed to accomplish over-all improvement in performance of welded ships.

Mr. Pellini's comments on the relation of direction of loading and performance of weldments are very pertinent. Some comments on this point have been added to the general discussion section of the paper since it was first submitted to Mr. Pellini and discussed by him. The directional properties of weld joints appear to be of paramount importance. More work of the type being conducted at the Naval Research Laboratory should be done on this subject.

Upper and Lower Transitions in Charpy Tests

Discussion by R. W. Vanderbeck

Messrs. Harris, Rinebolt and Raring have presented a very interesting paper showing that lower-velocity, lower-energy, multiple blows usually produce a sharp, lower transition when standard Charpy V-notch specimens are used, whereas the usual technique with high-energy blows produces a smooth curve with no distinct lower transition. This phenomenon certainly deserves further study so that the significance and cause of this behavior may be better understood.

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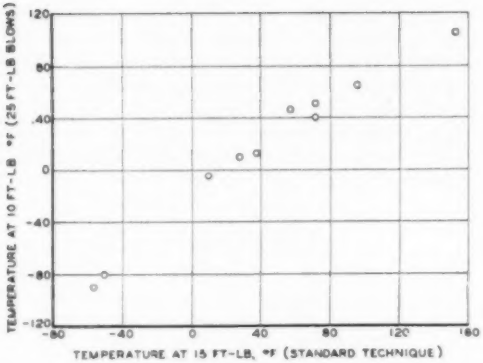
Paper by W. J. Harris, Jr., J. A. Rinebolt and R. Raring was published in the Research Supplement to the September 1951 WELDING JOURNAL, pp. 417-s to 422-s.

One item that may cause alarm is the fact that the lower transition and the 15 ft.-lb. transition on the standard curve do not correlate well with each other, as may be readily noted from the last two columns in Table 2. This is disturbing because both of these transitions are meant to rate the steels according to their relative ability to deform and behave in a ductile manner before cracking becomes extensive, and one might therefore expect them to show reasonable correlation. It may be seen in the adjacent graph, however, that good correlation is obtained if temperatures selected at the 10 ft.-lb. level using the multiple-blow technique are compared with the 15 ft.-lb. temperatures for the standard curve. The data obtained by the two different techniques do, therefore, rate the steels in a similar manner when certain arbitrary criteria are used in the evaluations. It does seem more logical to select the transition at the temperature at which a sharp change of behavior takes place, but it will be



noted from the authors' graphs that this transition occurs at quite different energy levels. For example, for Steel 1 the lower transition takes place in the 8 to 19 ft.-lb. range; for Steel 8 it occurs in the 22 to 38 ft.-lb. range. This seems to be the reason that the lower transition temperatures do not correlate with the 15 ft.-lb. temperatures on the standard curve.

The authors state that preliminary tests showed that the energy required for initiation of a small crack in the root of the notch was between 10 and 15 ft.-lb. I would like to ask whether this was so for steels 3, 4, 8 and 9, for it is on these steels that the lower transition is depicted as occurring above the 15 ft.-lb. level. If a shear crack initiated somewhere in the 10 to 15 ft.-lb. range, one would expect signs of an abrupt transition in this same energy range. Having hypothesized thus far, one can, by looking at the graphs, actually see some evidence of an abrupt transition taking place within this range. Whether or not small shear cracks are developed in the 10 to 15 ft.-lb. range can settle this question.

It would be easier to judge the true shapes of these curves if more tests had been conducted in the critical regions. Is it correct to assume that each point on the graphs represents just one test? If so, then a number of the curves are based upon very few data, and, as Rinebolt and Harris pointed out in an earlier paper,* the precision of the transition temperature measurements for such data would be rather poor. This may not be considered important for an investigation of this nature, but it makes it difficult to estimate the true behavior in certain instances when the data are limited.

Having read the authors' suggested reasons for the behavior observed using the low-energy technique, it still seems possible that speed of breaking can be one of the factors causing this different behavior. Not only striking velocity should be considered but also the velocity after the specimen has been partly fractured. It is difficult to separate the effects of striking energy and velocity for, given a certain striking velocity, the velocity after the specimen has been partly fractured will be less when the striking energy is less. The way to determine the influence of velocity would apparently be to keep the striking energy constant and vary the striking velocity. It seems important to learn why this lower transition is obtained using the authors' technique, and the suggested approach should help to decide whether velocity is an influencing factor.

* Rinebolt, J. A., and Harris, W. J., Jr., "Statistical Analysis of Tests of Charpy V-Notch and Keyhole Bars," THE WELDING JOURNAL, 30 (4), Research Suppl., 202-s to 208-s (1951).

Discussion by Captain W. P. Roop

More facts, to put with earlier interpretations, are here given on the two transitions. The paper is short, but this should not mislead the reader into underestimating its importance. That two transitions exist can now hardly be doubted. Some aspects of the new data deserve special emphasis.

The new facts and the authors' reasoning based on them may be viewed in light of two different principles:

1. The basic phenomena are to be seen at the crack-head, where the choice between static inception and active propagation must be made.
2. Associated with the crack is a strain-pattern and the nature of this pattern is affected by the metal at a distance as well as by that adjoining the crack-head.

The practical "problem arises from the fact that brittle fractures of structural members differ from 'brittle' fractures in most test specimens." In the specimens "brittle" fracture is preceded by plastic strain, hence the quotes on the word "brittle." The question thus becomes this: can brittle fracture in structures be identified with that other type of fracture in specimens which occurs at very low temperatures?

If so, we note immediately, we must account for the discrepancy in temperature at which fracture without large prior strain occurs in structures (*ca.* freezing) and in small specimens (−80° F. in Steel 1 and −90° F. in Steel 2 of the present data). It is a new feature of the present data that in most of the steels tested (Table 4) this discrepancy does not appear, and brittleness without prior strain occurs from zero upward, in Navy Specification Medium and High Tensile Steels. In samples taken from a ship the present tests show such brittleness at 0, 50 and 100° F. above the temperature at which it occurred in the ship.

The nonstandard feature of these tests lay in use of repeated low-energy blows. So far as total energy to the complete break goes, the authors are

W. P. Roop is with the United States Navy (Retired).

satisfied that it remains the same as in a test by a single blow. But the use of lighter and repeated blows reveals facts about the strain patterns which form the chief point of interest. Knowing what to look for, one can see the strain figures also in specimens broken at one blow. But every purpose except, perhaps, that of getting a simple and direct measure of energy would be equally served in a static test.

The stepwise drop in energy value at a definite temperature value is the most striking feature of the transition curves shown. But two other features are also noteworthy. First, in many cases this step comes at a temperature not far from the half value point; the new transition is thus not far removed from the more familiar one which has been so often noted hitherto.

Second, below the step the curve resumes a course which is a continuation of the more familiar curve above the step. In Fig. 5, e.g., we have a step superposed on a straight line. Instead of a second drop in energy it could be described as temporary increase over the normal value, abruptly abandoned.

The most important part of the paper is that in which these changes in energy with temperature are linked with the strain pattern. At the step an important part of the pattern disappears; below this limit the development of the pattern is confined to that spreading outward from the notch. That outward spread from the notch, however, shows no sign of a further disappearance at a still lower temperature, as would be necessary if fractures were to occur with no prior energy absorption at all. There is only one step; the further approach toward zero is gradual.

The point at which the crack appears in course of a test is regarded by the authors as significant; they have looked for it with a 10-power glass and found nothing short of a limit between 10 and 15 ft.-lb. and this is the same at all temperatures above the step. Below the step "the crack forms prior to the strain markings and thus allows relief from further strain behind it." From these observations they pass to the conclusion that the step-transition is linked with crack inception and the gradual transition with crack propagation. This is in general agreement with the Lehigh result except for the question as to how far the temperatures of the two transitions may be separated.

This is a point worth close attention. Note first that the pattern in Fig. 7 (*B*), with a single Luders Vee, exists only at a stage in progress of the test before advance of the crack has begun. Presumably when it does start forward, the crack will carry the Vee forward with it, filling out the inside of the Vee with a succession of such Vees. Behind it, as the authors say, the crack leaves the metal relatively little strained, *outside the Vee*. Inside the Vee the strain remains what it became as the crack approached; after it has swept across, the pattern consists of a wedge of highly strained metal (Zone C), surrounded by a region of low strain (Zone A).

Above the step, as in Fig. 7 (*A*), the energy absorbed in Zone A is higher. The whole process may be described by saying that energy in Zone A drops off gradually with temperature. At the upper end of the step this decrease is arrested; energy begins to go somewhere at a rate not much affected by temperature. At the riser of the step, however, this effect stops abruptly and the gradual decrease (in Zone A) is resumed.

Where in the strain pattern does this stepwise energy go? Is there a temporary increase in the absorption of energy within the Vee (Zone C)? The authors seem to think not so. I suggest that the way forward lies in clarifying the facts about shifts in strain pattern with temperature.

And beyond this lies the need for more facts about the effect on the strain pattern of geometry, especially the effect of size. The only data of this sort here offered refer to notch depth which was gradually increased, presumably at the expense of the remaining metal in the net section. The specimens were broken under conditions of full ductility ("fibrous fracture"). Supposing that the bars were $^1/_2$ in. thick and the initial notch $^1/_8$ in. deep, the net section was reduced in $^1/_{40}$-in. steps from $^3/_8$ to $^1/_4$ in., where the strain markings represented by the inverted triangle disappeared.

By a geometrical change the same shift in the strain pattern was thus obtained as by a reduction of temperature with the standard geometry.

There is, therefore, a *qualitative* equivalence between larger size and lower temperature in effect on the strain pattern, and hence also on the energy absorbed. I suggest that the conversion of this result into a *quantitative* equivalence might well be taken as the chief objective of further work.

Authors' Reply

The authors are grateful to Captain Roop and Mr. Vanderbeck for their comments and questions.

Captain Roop's argument that a more complete understanding of transition might be realized by study of the energy density in the various zones as temperature is varied has always appealed to the authors. It is considered, however, that the small size, the complex and varying stress-state and lack of control in the notch-impact test renders this test less suitable for such studies than the wide-plate specimen, which Captain Roop used. In the future it is hoped that energy-distribution studies in wide-plate tests will be extended to the lower transition region in which plastic flow is nearly eliminated. In specific comment on a portion of Captain Roop's discussion, we should like to point out that while, as he says, the temperature difference between the average-energy transition and the lower transition is not great in many cases, it is great in more than half of the cases. The lower transition is often far from the more familiar one.

Both discussors take notice of the fact that the absolute value of the energy levels at the top and at

the bottom of the step at the lower transition varies widely among the various steels. This is obviously an interesting point, but discussion of it was omitted in the paper because it seems not to be germane to the phenomenon associated with or responsible for the lower transition, viz., the behavior of the metal at the root of the notch. Figure 1 illustrates the observations upon which this reasoning is based.

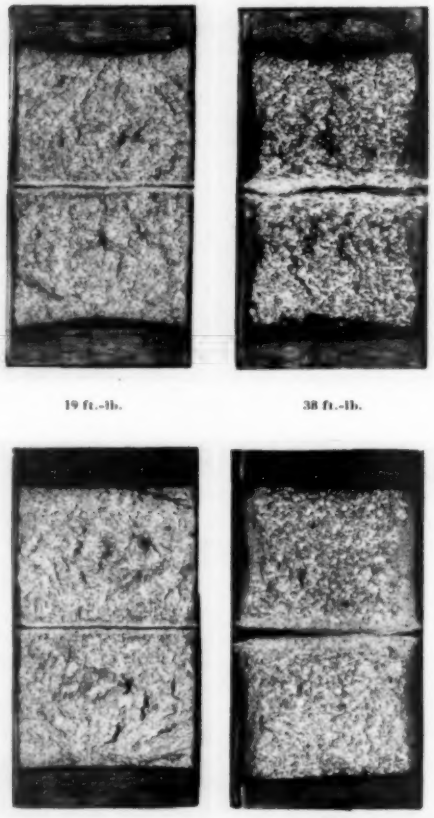


Fig. 1 Specimens broken above and below lower transition temperature

(*Top*) Above lower transition. (*Below*) Below lower transition

At the lower transition, the energy absorption of Steel 1 dropped from 19 ft.-lb. to 8 ft.-lb., whereas that of Steel 9 dropped from 38 ft.-lb. to 19 ft.-lb. It will be noticed that the two steels display similar behavior in passing through this lower transition in that there is a small fibrous patch just below the notch in the specimens broken above the lower transition, whereas this patch is absent in those broken below the lower transition. It is clearly evident, however, that the fracture faces of the two steels differ with respect to the amount of fibrous fracture along the sides of the specimen; Steel 9 has a much thicker shear lip along the sides than does Steel 1. It seems, therefore, the ductile action along the sides has the effect of influencing the absolute value of the energy absorption at temperatures below or above the lower transition, but is not associated with the energy step *per se*.

After consideration of the preceding discussion, it can be seen that one would not expect an arbitrary energy level necessarily to correlate with the lower transition.

To answer Mr. Vanderbeck's specific question, which seems to be closely associated with the above discussion, small cracks did develop in the notch root when steels 8 and 9 were struck with 10 to 15 ft.-lb. blows at temperatures above the lower transition; when these two steels were struck with such blows at temperatures below the lower transition, cleavage cracks developed at the notch root and ran about half way through the specimens before the energy absorption at the sides arrested further progress of the crack. Unfortunately, steels 3 and 4 were tested with 25 ft.-lb. blows only; consequently it is not possible to say that a 10 to 15 ft.-lb. blow did start a shear crack.

In answer to Mr. Vanderbeck's second question, each point on the graphs represents but one test, and it is agreed that the transition would have been defined with greater certainty, with the exception of the results of tests of Steel 2, if more specimens had been broken, but since the work was essentially exploratory, it was deemed preferable to deploy the efforts by using fewer tests on a larger number of steels in order to determine whether or not the effect would be observed in different materials.

The authors concur with Mr. Vanderbeck's opinion that the velocity of the tup might well be a factor which could account for the apparently greater sensitivity of the lower-velocity testing technique, and they agree that it should be added to the other factors suggested in the paper.

Progress Report No. 5—Welded Continuous Frames and Their Components

Residual Stress and the Yield Strength of Steel Beams

Analytical and experimental study of the elastic and plastic behavior of welded continuous steel beams. Stress concentration, residual stresses and other factors which affect the yield strength of steel members are discussed. Basic assumptions of the simple plastic theory are compared with the test results. The influence of residual stress on buckling strength of columns is also included

by Ching Huan Yang, Lynn S. Beedle and Bruce G. Johnston

(I) INTRODUCTION

UNDER certain conditions continuous or "rigid" frames require less material than statically determinate structures designed for the same loads. In conventional elastic design methods, structures are designed with respect to the load at which the calculated maximum stress reaches the yield point, henceforth called the "initial yield load" of the structure. In the case of statically indeterminate structures (and to a lesser degree in determinate structures), a further increase in load may be realized even though yielding has occurred at some cross sections.

Use of the so-called "simple plastic theory" has been suggested by a number of authors who have recommended design on the basis of ultimate strength.[5, 15, 19] It has been suggested that increased economy can be achieved if the design can be based on a load greater than that at initial yield.

Questions are occasionally raised with regard to the possible application of the simple plastic theory. One reason for such inquiries is that too little is known regarding the basic plastic behavior of steel structures. A study of the literature reveals, for example, that most of the previous experimental work involved specimens made of rectangular-shaped sections and test models were usually normalized or annealed before test. Test models were restricted in size. Some early pioneer work was carried out by Maier-Leibnitz* on rolled steel joists. I-shaped members (not WF) of 6 in. depth were tested as continuous beams.

This report is one of a series in which the elastic and plastic behavior of full-size steel members and frames are being studied.[1-4] In addition, the limitations and possibilities of plastic design and plastic analysis are being explored in this project being carried out at Lehigh University in the Fritz Engineering Laboratory under the direction of the Lehigh Project Subcommittee of Welding Research Council.†

In order to investigate the behavior of welded continuous frame structures, a series of tests on simulated frames and continuous beams were carried out to furnish additional information regarding elastic and initial plastic deformations and to correlate these results with existing analysis and design procedures. Single span beams with overhang were used to simulate continuous beams and frames with constant moment of inertia. Rolled steel wide flange sections were used and all the beams had an over-all length of 28 ft. The members were tested in the as-delivered condition since the purpose of this program was to simulate the behavior of real structures as closely as possible.

It has been established that welding may introduce in structural members residual stresses of the same magnitude as the yield stress of the base material. Connection details introduce local concentrations of stress. Also, structural steel members in the as-delivered condition contain residual stresses due to cooling after rolling. The effects of these factors on the initial yield load have been observed and analyzed in this paper. The buckling strength of columns or beams under certain conditions will be reduced by the presence of residual stress and a brief examination is made of this influence.

Reserved for later reports are studies of the ultimate strength and deflections of continuous beams, inelastic local and lateral buckling of steel members, and shear failure in webs of WF sections.

(II) TEST PROGRAM

(*I*) *Test Setup*

The setup for the continuous beam program is shown schematically in Fig. 1. A beam, shown under test in Fig. 2, rests on two rollers that are, in turn, supported

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* A translation in abstract form of this paper which appeared in *die Bautechnik* (1, 11-27, 1928) is available from the Fritz Engineering Laboratory.

† Members of this Subcommittee of the Structural Steel Committee are: T. R. Higgins, *Chairman*, A. Amirikian, Lynn S. Beedle, H. C. Boardman, J. M. Crowley, S. Epstein, F. H. Frankland, LaMotte Grover, L. E. Grinter, H. D. Hussey, B. G. Johnston, J. Jones, C. Kreidler, H. W. Lawson, Bureau of Ships (Code 350, J. Vasta and E. M. MacCutcheon), N. M. Newmark, A. E. Poole, C. E. Webb and W. H. Weiskopf.

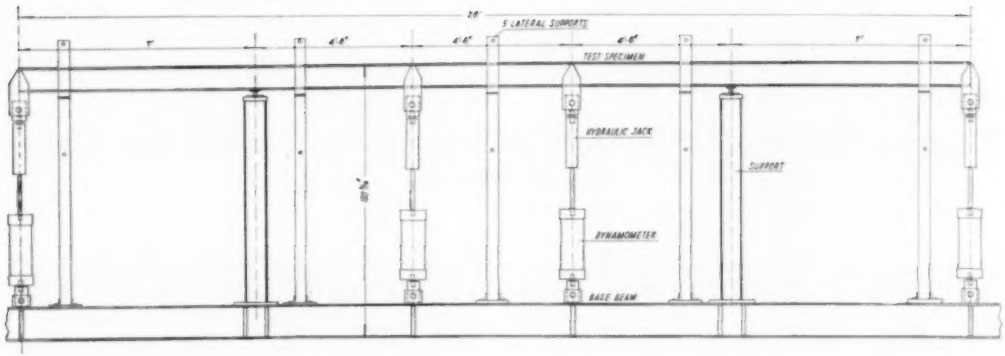


Fig. 1 Continuous beam test setup. Concentrated loads are applied at third points of central span and end loads are used to bring specimen to proper load condition

by two columns. A 14WF136 section is used as the base beam.

Loading equipment, dynamometers and instruments are similar to those described in Progress Report No. 2.[2]

A bracing frame was used to prevent lateral deflection, Fig. 3. The surfaces of the vertical guides were lubricated prior to the test, and the specimen was allowed to deflect vertically with only slight friction. A "friction" test was conducted prior to each main test to assure this condition. Such a bracing frame as shown in Fig. 3 will not prevent all motion in the lateral direction and more recently an improvement has been made in the design. The newer method of support is of the flex-bar type, a larger percentage of the lateral motion being prevented.

Apparatus for testing the control beam was identical to that used in the previous beam test program.[1] Over a 14-ft. span, third-point loading was applied through rollers on special loading brackets.

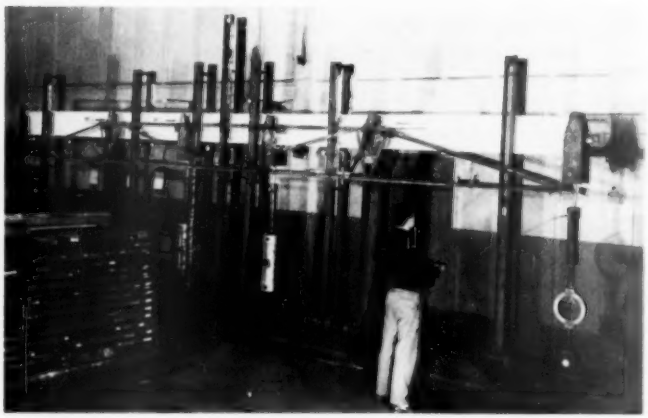


Fig. 2 Continuous beam B7 under test

(2) *Test Program and Preparation of Specimen*

One simply supported control beam and five continuous beams were tested, as listed in Table 1.

Except for B3, all the continuous beams were tested to simulate a "fixed-ended" beam of 14-ft. span, thereby also simulating the interior span of a continuous beam of many spans. This was accomplished by applying load at the ends of the overhanging portions sufficient to return the member to a level position at the supports after the application of each load increment. In Test B3 less than full restraint was provided at support points, the cantilever ends being maintained at the same deflection as at the supports; thus a single bay portal frame was simulated. Loading carriers welded to the specimen at each load point brought the applied load directly to the web of the beam, Table 1.

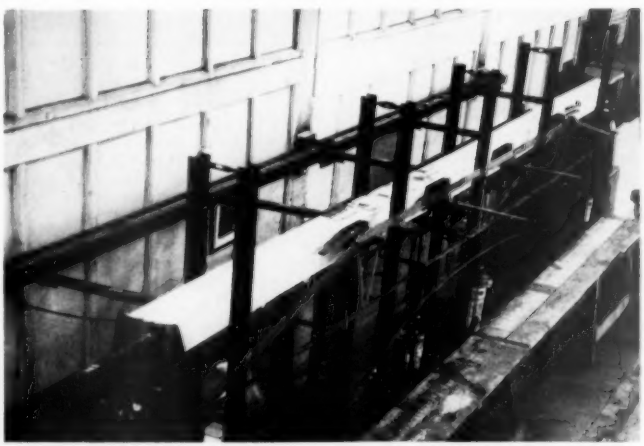
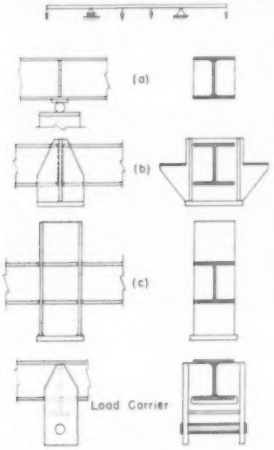


Fig. 3 Vertical guide supports system designed to prevent lateral displacement

Table 1—Tests Conducted on Simulated Continuous Beams and Frames and on Control Beam (B1)



Connection Details

Test Number	Size of Member	Loading	Support Detail
B_1	8WF40 (I)		
B_2	"		a
B_3	"		a
B_4	"		b
B_5	"	"	c
B_7	14WF30 (I)	"	b

Table 1 also shows the different details used on identical tests (B2, B4 and B5) in order to give a range in the magnitude of possible welding effects including residual stress and stress concentration. In any one beam the same detail was used at each support. Case (*a*) is the simplest form. The splice plate of Case (*b*) involves more welding and is a common structural detail. Case (*c*) which involves the greatest amount of welding is typical of an interior connection.

In addition to the variables of stress concentration, type of connection and of end restraint, a third variable studied in preliminary fashion was that of shape of section. B7 is identical with B4 except that a 14WF30 section was used rather than the 8WF40 shape. The former has the proportions of a beam section while the latter is a "column" section.

All specimens were tested in the as-delivered condition and had section properties as shown in Table 2. Tension and compression coupons were tested from representative positions in the members.

(3) *Strain Gages, Deflection Gages and Level Bars*

About sixty SR-4 strain gages were used on each test. Those near the support points of the beam were used to obtain the strain distribution in the elastic and plastic ranges to make possible a study of the combined effects of stress concentration, residual stress and the change of mechanical properties of the material due to welding. AX-5 type strain gages were mounted on the web of the beam in

Table 2—Section Properties of Test Specimens

Beam section		*Area, in.²*	*Depth, in.*	*Flange* — *Width, in.*	*Flange* — *Thickness, in.*	*Web thickness, in.*	I_x, in.⁴	Z_x, in.³
8WF40	Handbook	11.76	8.25	8.077	0.558	0.365	146.3	
	Measured	11.66	8.32	8.060	0.552	0.370	147.0	39.65
	% variation	−0.85	+0.84	−0.87	−1.07	+1.37	+0.05	...
14WF30	Handbook	8.81	13.86	6.733	0.383	0.270	289.6	
	Measured	9.11	13.78	6.820	0.382	0.281	295.3	48.35
	% variation	+3.33	−0.06	+1.50	−0.34	+1.1	+2.05	...

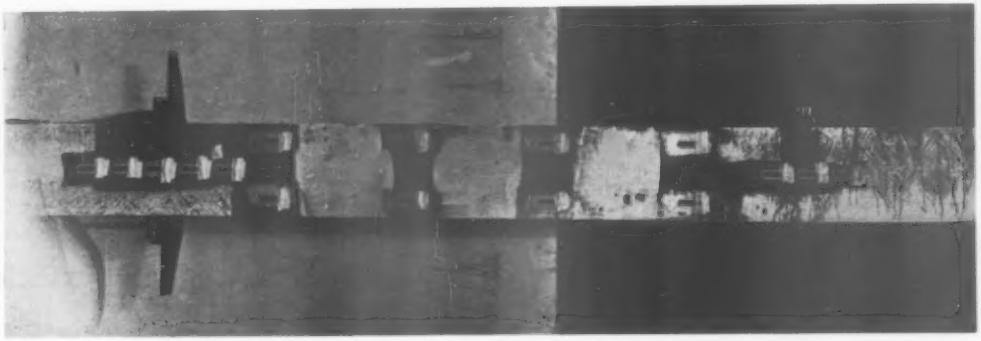


Fig. 4 View of top flange of B3 between support (left) and load point (right) showing typical arrangement of SR-4 gages

the region of maximum shear stress. Uniaxial strain gages were also mounted along the pure bending section of the beam to secure data for experimental M-ϕ curves. A typical strain gage layout on a test specimen is shown in Fig. 4.

On each continuous beam test deflections were measured at thirteen points along the beam, using Ames dial gages. Measurements were referred to the neutral axis of the beam at the support points by means of the deflection gage supporting rig. The detail at the beam support point is shown in Fig. 5. Dial gages fitted with sharpened points were mounted on B4 and B5 between the upper and lower flanges near the supports to measure the local buckling of the compression flange.

Rotations at each load point were measured with level bars. In the test of beam B3 rotations were measured at the support points as well, Fig. 5. In the remainder of the program zero angle change was maintained at the supports.

On all tests except B2, two level bars were mounted perpendicular to the longitudinal axis of the beam to measure lateral buckling rotation of the central span. Level bar supports mounted on load carriers may be seen in Fig. 17.

Whitewash (hydrated lime) was applied to indicate the yielding pattern and the progression of yield zones.

(4) *Test Procedure*

The sequence of load increments, measurements, etc., was outlined before each test. Readings were set on the dynamometer strain indicators and loads were applied slowly, evenly, and in small increments to hold the reading and maintain constant the test condition of the specimen. Readings of dial gages, level bars and SR-4 gages were then taken.

When yielding occurs under constant load in the plastic range, a specified period of time must elapse to permit the penetration of yield zones into the specimen. An arbitrary criterion was adopted for taking readings under such circumstances as follows: When the increase of deflection in the central dial gage of the beam was less than 0.002 in. within a period of 15 min., a complete set of readings was taken. The test then proceeded with another increment of load. Even this procedure meant that a single test required a considerable amount of time, usually approaching a week of continuous testing on a 24-hr.-per-day basis.

All tests except one were carried through the plastic range without interruption to avoid the discontinuous increase of strength of the beam introduced by the effect of strain aging. (Such an effect was observed in a previous investigation.[1]) In the control beam test B1 loads were returned to zero after each increment to measure the permanent set.

Loads were kept constant while readings were taken. Curves of some deflection and strain data were plotted against load during each test as a check on the proper functioning of apparatus.

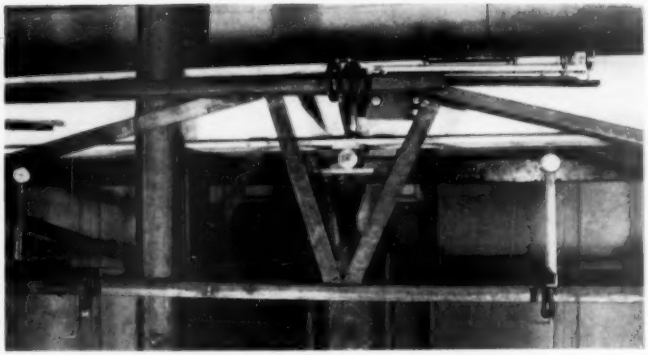


Fig. 5 Test B3 showing detail of deflection gage rig at support point. Level bar was used to measure rotations at supports

(III) BENDING STRENGTH OF WIDE-FLANGE SECTIONS UNDER PURE MOMENT

(1) *M-ϕ Relation of Bending Members*

In elastic and simple plastic beam theory the strain due to bending is assumed to vary linearly over a cross section normal to the axis of the beam. The stress and strain relation for each fiber of the bent member is assumed to be the same as that determined in a simple tension test. Tension and compression properties are assumed identical. The results of coupon tests are given in Appendix A.

In accordance with the assumptions of beam theory and assuming that the material does not exhibit an upper yield point, the M-ϕ relation for a WF section has been computed and is plotted in Fig. 6.* It is based on an idealized stress-strain diagram that consists of two straight lines. At Point *1* the elastic limit has

* Calculation of M-ϕ curves has been made in Progress Report No. 1.[1] ϕ, the curvature, is the unit angle change and is measured in radians per inch.

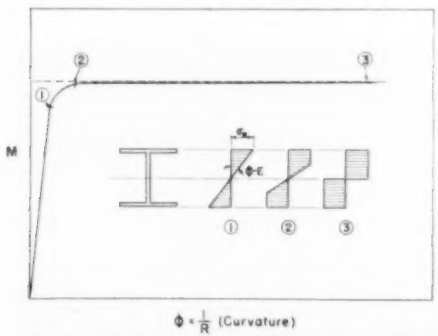


Fig. 6 Moment-curvature (M-ϕ) relationship for WF shape according to the Simple Plastic Theory. Corresponding stress distributions are shown for various points on the curve

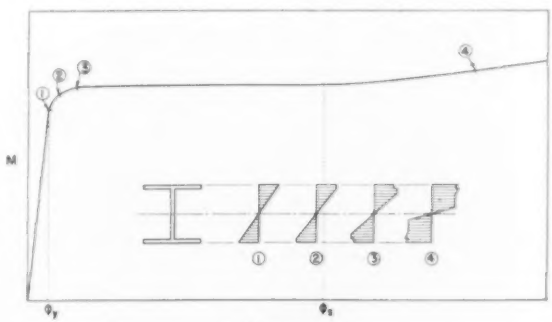


Fig. 7 M-ϕ relationship for WF shape, due account having been taken of strain hardening

Fig. 8 (right) Experimental M-ϕ curves determined from SR-4 gage measurements in the central span of four continuous beams

been reached and $\phi_y = M_y/EI$. At Point 2 the member is partially plastic. The bending moment in the beam section will approach a limit, Point 3, as ϕ becomes very large. The limiting moment is called the "plastic hinge moment," M_p.

$$M_p = \sigma_y Z,$$

where

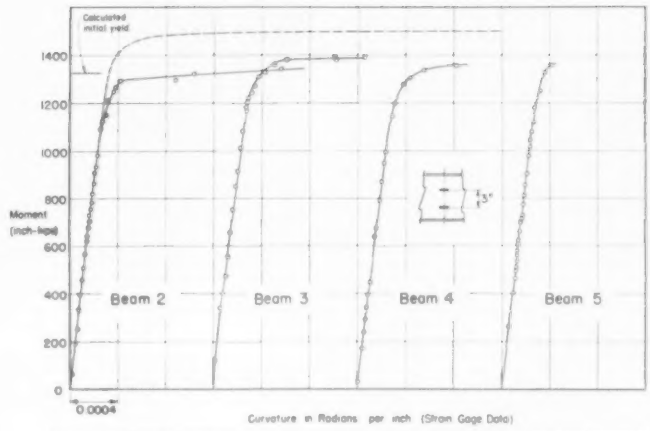
Z = plastic modulus; the static moment of the entire cross section about its neutral axis.
σ_y = lower yield point stress.

In the simple plastic theory (typified by Fig. 6) the strain-hardening effect of mild steel is neglected.[8, 10] Considering the strain-hardening effect measured on a number of test coupons a theoretical M-ϕ curve is shown in Fig. 7 and is based upon test coupon measurements carried well into the strain-hardening range. Strain hardening commences when the unit rotation reaches ϕ_s (ten to twenty times the yield-point curvature) and at Point 4 strain hardening is evident in the stress distribution. The web material has a higher yield point than the flange and this has been taken into account as shown in the stress-distribution at Point 3. Equations for calculating points on this curve have been published.[4]

The theoretical curves in both Figs. 6 and 7 are based upon the further assumptions that no local buckling occurs and that residual stresses are absent.

Experimental M-ϕ curves of continuous beams B2, B3, B4 and B5 plotted from deflection and strain gages are shown in Figs. 8 and 9. Similar data for control beam B1 are given in Figs. 10 and 11. These curves, which extend only into the early plastic range, show that the observed plastic strength is as much as 10% lower than the predicted value. On the other hand it has been observed in tests of annealed 4-in. I-beams at the Fritz Laboratory that higher strengths than the calculated values were indicated by the M-ϕ curves.

These discrepancies between experiment and theory result from the rather crude assumption in the theory that plastic strain is uniformly proportional to the distance from the neutral axis of the beam. When yielding begins in the flanges of a WF section, the plastic strain is assumed to be uniformly distributed as shown in Fig. 12 (*1c*). Actually, local plastic zones are formed due to stress concentration and they penetrate the beam much deeper than assumed in the



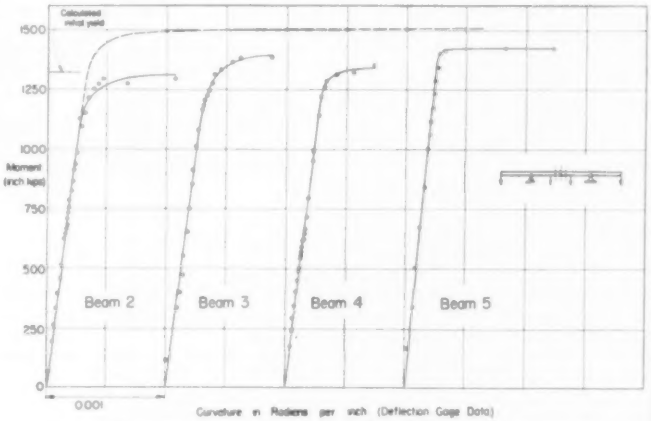


Fig. 9 M-ϕ curves determined from deflection gage measurements

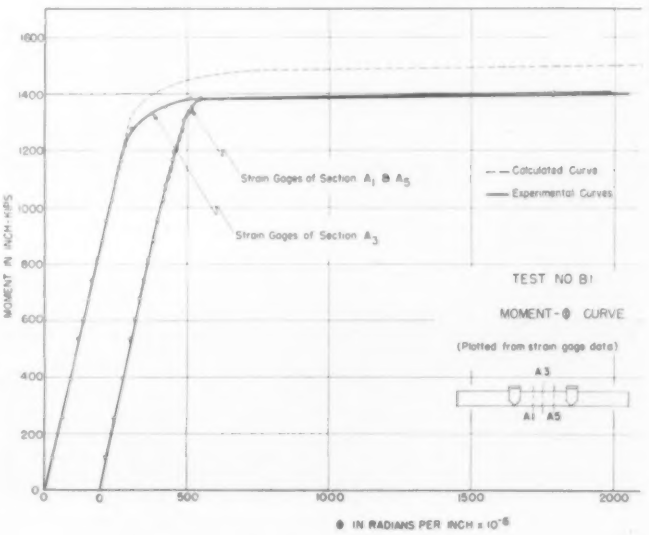


Fig. 10 (right) M-ϕ curves for control beam B1 as determined from strain gage measurements

theory as in Fig. 12 (*1d*). At the same time some regions in the outer fiber of the flange are still in the elastic range. Figures 13, 14 and 15 (tests B3 and B7) show such localized yield zones as revealed by whitewash. The different stages of yielding are evident, with lines which penetrate to different depths. Yielded zones in highly polished rectangular specimens have been photographed by Roderick and Phillips.[16] Kollbrunner[13] tested a series of I-beams and observed that the specimens yielded in a layer by layer action. Thence, he concluded that the material cannot be considered as quasi-isotropic in the plastic range.

Thus the stress and strain relation as described in connection with Figs. 6 and 7 cannot hold true either at the plastic zones or in the elastic zones of a section under the same moment. For a beam under a certain constant moment, the average value of ϕ of the member will depend on the number of local plastic zones initiated. Since the initiation of local plastic zones is affected by stress concentrations, residual stresses and nonuniform mechanical properties of the material, the ϕ-value at a cross section of a bending member is therefore not a function of the moment alone. Different ϕ-values may be obtained at a section under the same moment due to the presence of the above factors. Since the geometric shape and heat treatment of the bending member will affect stress concentration and residual stresses, the early part of the M-ϕ relation of the member is consequently also affected by them.

Thus, depending directly on the mode of yielding of structural steel and indirectly on stress-concentration and residual stress, a larger or smaller ϕ-value is obtained at a particular moment. This means that the simple plastic theory will not predict structural behavior as closely as elastic theory since the assumptions are but rough approximations to what actually happens in the structural member.

Although no positive proof is given, the fact that as-delivered specimens consistently show a lower strength than that predicted by the simple plastic theory (based on the measured material properties) may thus be explained partly on the basis of stress concentration and residual stress in the member. There are an increased number of local plastic yield zones, and the formation of these local plastic zones in the beam section will result in a higher ϕ-value even though the moment is kept unchanged since portions of the beam yield which are assumed to be elastic in the theory.

Referring to Fig. 14, this photograph of Beam B7 was taken at a moment of 1580 in.-kips. well below the predicted yield moment of 1640 in.-kips. The yield zones are just beginning to penetrate into the web and the measured ϕ-value is about 0.00026 rad./in. as determined from an average of strain measurements (Fig. 24). In Fig. 15 the moment on the section under pure bending is 1611 in.-kips., still below the theoretical initial yield moment, but the ϕ-value has increased to about 0.00035 radians per inch as the yield zones extended further toward the neutral axis.

Similar evidence is available from the tests in which an 8WF40 section was used. Referring to Fig. 16 (M = 1150 in.-kips., ϕ = 0.00032 rad./in.), yield zones have formed in the compression flange.* Figure 8 shows that this yielding was accompanied by a sudden increase in ϕ due to the formation of yield zones at this load. In Fig. 17, yield zones are shown in the compression flange of the central portion of B3 at a moment of 1250 in.-kips. (the calculated yield moment is 1325 in.-kips.).

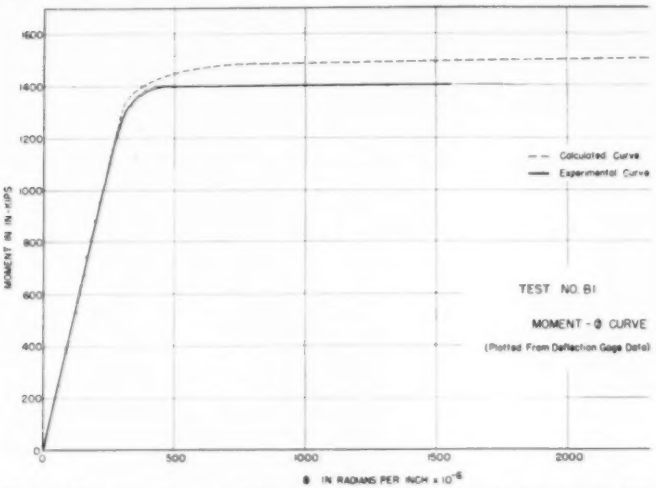


Fig. 11 M-ϕ curves for control beam B1 as determined from deflection gage data

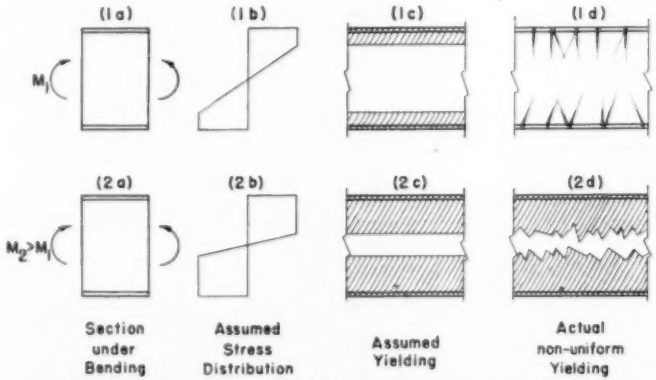


Fig. 12 Assumed and actual yield zones in structural steel beams

Fig. 13 Yield zones in central span of 8WF40 beam (B3)

* The formation of these lines will be discussed later.

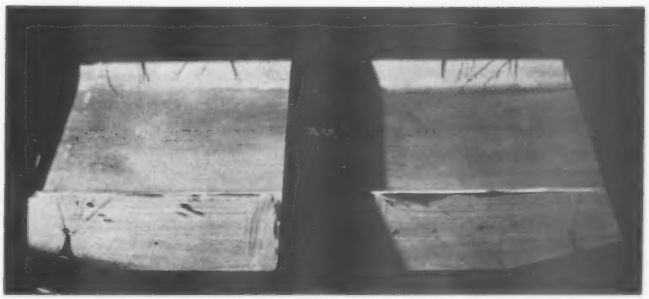


Fig. 14 View looking up at B7 (14WF30) showing yield zones in compression flange commencing to penetrate into the web

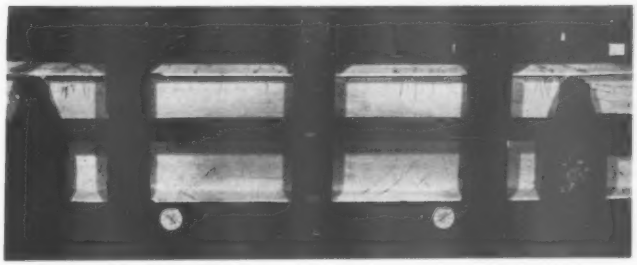


Fig. 15 B-7 showing further development of yield zones

The measured curvature of 0.00036 rad./in. (Figs. 8, 9) is greater than predicted by the theory.

As the rotation of the member increases, the plastic zones spread toward the neutral axis and the strain distribution of the actual case (Fig. 12 (*3d*)) then approaches the one assumed in the theory as in Fig. 12 (*3c*). At the larger rotations the moment should approach that predicted by the simple plastic theory.

This hypothesis has been confirmed by test results as indicated in the M-ϕ curves plotted in Fig. 18. These M-ϕ curves for three different beams were plotted from strain gages located near the support as shown in the same figure. A discrepancy between the experimental and theoretical values is shown in the early part of the curves, but the experimental curve approaches the theoretical value as the plastic zone extends closer to the neutral axis of the beam.

It is emphasized that the measurements of Fig. 18 are near a support in a region of moment gradient. Thus large local unit angle changes are restricted to a relatively short length of beam. In the center, however, where the moment is uniform, a very large over-all rotation is required before the local rotations become large. This is evident from Fig. 19 where, in spite of the large rotations, the ϕ values are still less than those coincident with strain hardening.

Figure 18 shows that the later increase in moment with increase in ϕ occurs prior to the onset of strain hardening, the slope of the experimental curves being greater than any measured in a region of strain hardening. The theoretical curve of Fig. 18 is based on the measured material properties and takes strain hardening into account.

Suppose now, that the member is well annealed, removing the cooling and welding residual stresses. Better agreement with theory in the early part of the M-ϕ curve is observed. In the 4-in. annealed I-beam tests mentioned earlier, the observed strength was higher than the predicted value. Figure 20 shows such a beam. Yield zones, evident from the white wash, are not distributed along the beam in the section under uniform moment (as was the case for as-delivered specimens) but are concentrated near the load points. Yielding was initiated at the load points due to stress concentration; as further load was applied, the yield zones gradually progressed toward the center of the beam span from each support. The measurement of ϕ was made at the center. Thus the central portion, though under the same moment, was still in the elastic range while the section near the loading points went very far into the plastic range. No plastic zone started at the central portion, possibly because the annealing process made the mechanical properties of the beam quite uniform.

On the other hand, the beginning of plastic zones in the continuous beam tests was quite different. In the central span which was under constant moment, yield lines were initiated at several places when the load reached a certain value, as shown in Figs. 16 and 17. Residual stresses introduced due to cooling after rolling in the continuous beam probably are the reason for the initiation of more plastic zones in as-delivered beams because the mechanical properties are not uniform.

The behavior observed in the annealed 4-in. I-beam tests is in confirmation of the phenomenon that a lower stress is required to begin a slip band adjacent to one already formed than to initiate an original band.[22] The stress-relief anneal for the member was probably effective in making uniform the mechanical properties, increasing the ratio of upper to lower yield point (this effect was actually observed in some of the beam tests),

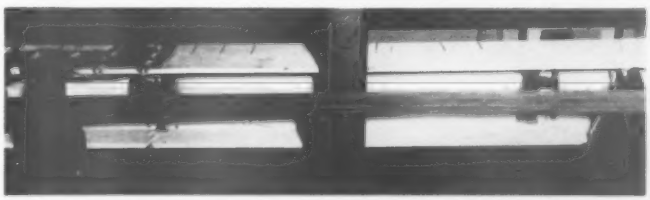


Fig. 16 Yield lines formed in compression flange of B2 due to cooling residual stress. (The pattern has been accentuated by tracing the original lines in ink)

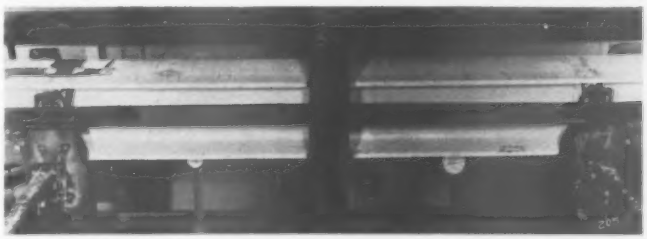


Fig. 17 Yield lines formed in compression flange of B3 due to residual stress

facilitating the formation of slip bands adjacent to ones already formed rather than in other places along the beam.

The M-ϕ curve for Beam B7 (14WF30 section) is plotted in Fig. 21. Owing to its geometric shape, severe local and lateral plastic buckling was observed in this specimen. Thus this M-ϕ curve failed to reach the calculated value even after yielding penetrated deeply into the web, Fig. 22. The problem of plastic buckling will be discussed in a later report.

In engineering design, due to the fact that the deflection of a structure must usually be held within a certain limit, the early part of the M-ϕ curves will be a region of importance.[3] Thus, the reduction in strength (due, indirectly, to residual stress) imposes a possible limitation on the use of plastic design methods. The supports of a completely restrained beam must rotate about eight times the elastic limit value before the last plastic hinge is formed.[4] This is beyond the value at which the moment is less than predicted for the example shown in Fig. 13 so that no over-all reduction would be experienced. However, if the last "plastic hinge" were in a uniform moment section then a reduction in strength is to be expected if one is to ignore the counteracting influence of strain hardening.

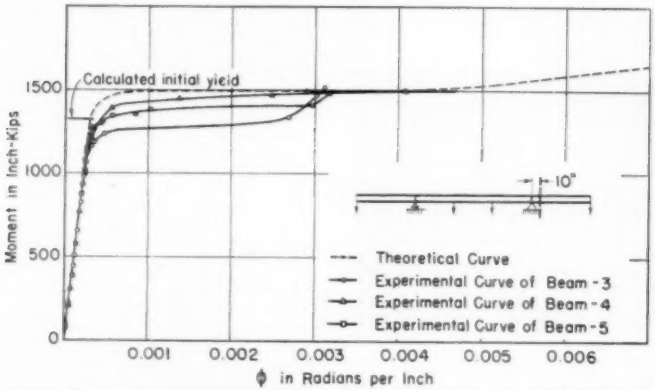


Fig. 18 Moment-curvature relationship of continuous beams of 8WF40 shape at a section near a support

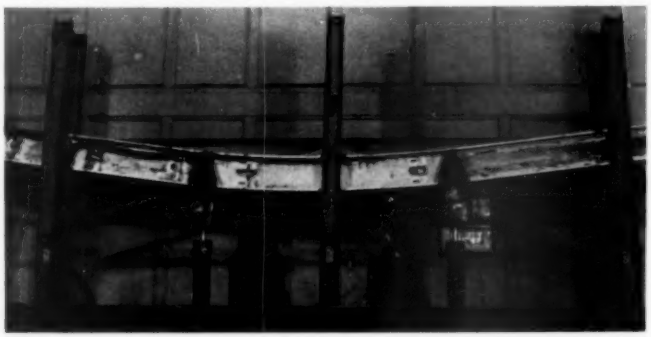


Fig. 19 Beam 2 at end of test

Fig. 20 Annealed 4-in. I-beam (7.7 lb./ft.) showing progression of yield zones from load points toward beam center

(2) *Strain Distribution in Plastic Bending*

In the previous section it was pointed out that in the early part of the plastic range, local plastic zones are initiated in the constant moment portions of the continuous beams. It seems obvious (and has been observed) that the assumption of linear strain distribution does not hold true in the plastic range. When the beam is also under shear force due to a transverse load, this assumption is even further from the actual case. Figures 23 (*1*), B7, and 23 (*2*), B2, show the strain distribution in beam sections under pure bending. Figure 23 (*3*) shows the strain distribution of a beam section under bending and small shear force. Figure 23 (*4*) shows a section under bending and high shear force. These diagrams indicate that the assumption holds very well in the elastic range, but not in the plastic range.

The discrepancy between the assumed and the actual strain distribution at one section may be very high, but the integrated angle change and deflection over a certain length of the beam by using the assumption may still give close agreement with the test results.

Actually the deformation curve of a member under bending in the plastic range is determined by the portion which remains elastic. It is not necessary that the strain in the plastic region be proportional to the distance from the neutral axis. The magnitude of it can be any value larger than ϵ_y, the maximum elastic strain, if strain hardening is not considered.

M-ϕ curves plotted from measurements of strain on the webs of tested beams show that the M-ϕ relation of a section is not much affected by the localized plastic strains in the outer fibers which were seen in Fig. 23. Figures 24 and 25 show

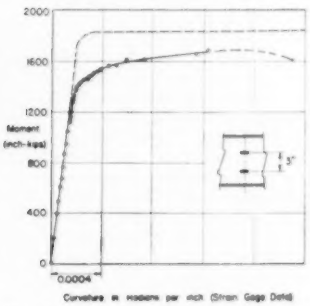


Fig. 21 M-ϕ curve for B7 (14WF30) near a support point

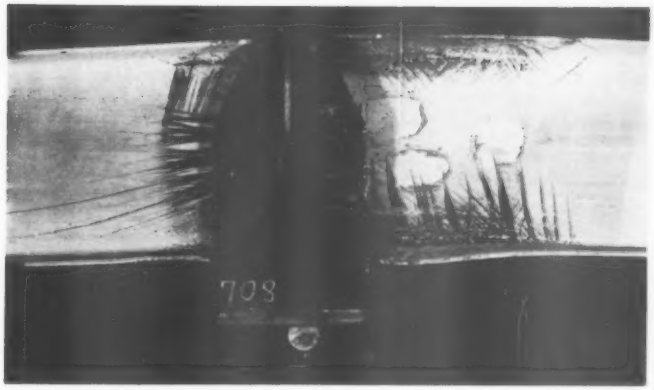


Fig. 22 Local buckling of 14WF30 shape

the M-ϕ curves of two different sections of Beam B7, one under pure moment and the other under bending moment and small shear force. Considering each figure separately the three sets of gages are in reasonable agreement with one another.

(IV) YIELD STRENGTH OF CONTINUOUS STEEL BEAMS

(1) *Factors Affecting the Yield Strength of Steel Members*

In structural design, calculation of the initial yield load usually excludes such factors as residual stress and stress concentration. The nature of these factors is discussed in the following paragraphs and some typical residual stress distributions are shown.

(a) *Residual Stress Due to Nonuniform Cooling After Rolling.* As-delivered rolled sections contain residual stresses caused by uneven cooling after rolling. Since the finishing rolling temperature of steel sections is above the recrystallization temperature, it is not likely that rolling, as such, introduces residual stress.

As an example of the formation of residual stress due to uneven cooling in a WF beam, assume that the temperature after rolling is uniform and that there are no residual stresses in the section. The cooling rate at the central part of the flange is lower than at the edges. The greater contractions of the two edges due to the proportionately higher cooling rates would cause compression stresses at the central part of the flange and tensile stresses at the two edges. If no plastic flow occurred during cooling, this thermal stress would disappear when the temperature again became uniform. It is known, however, that the tensile or compressive strength of steel is low at high temperature. Compressive thermal strains introduced at the center may exceed the corresponding compressive strength during cooling. Plastic flow will then take place at the central part of the flange. Subsequently, when the member is cooled to room temperature, the central portion of the flange will be left with tensile residual stress and the edges with compressive residual stress.

The residual strains measured in the flanges of WF sections in Progress Report 1[1] are reproduced in Fig. 26. As expected, the edges are in compression and the center is in tension.

The initiation of yielding and progression of yield lines in the continuous beam tests may be deduced from the known residual stress pattern. Measurements show that the compression residual stress at the edge of the flange is higher than the tensile stress at the center. This has also been observed by other investigators.[20]

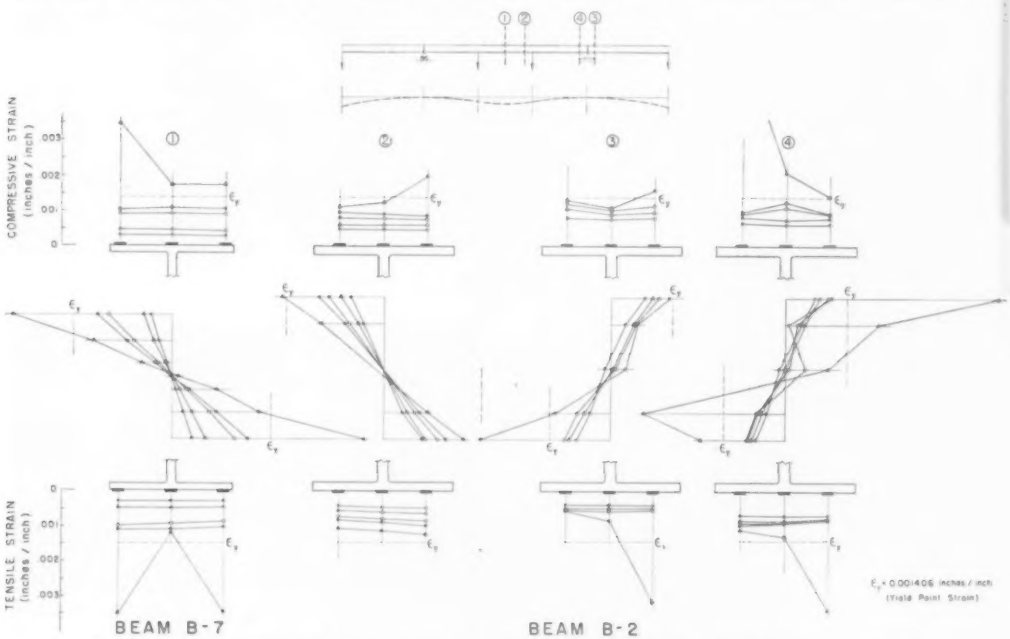


Fig. 23 The distribution of strain at various loads and at different cross sections of beams B2 and B7

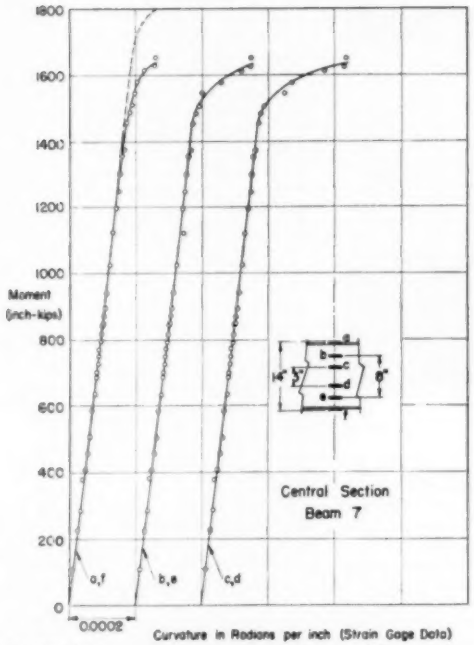


Fig. 24 M-φ curves at the central portion of B7 as determined from three sets of strain gages

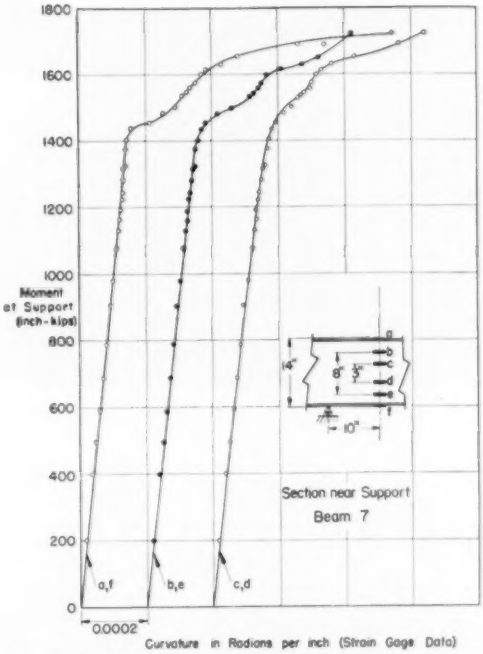


Fig. 25 M-φ curves at a section near the support of B7 as indicated by three sets of strain gages

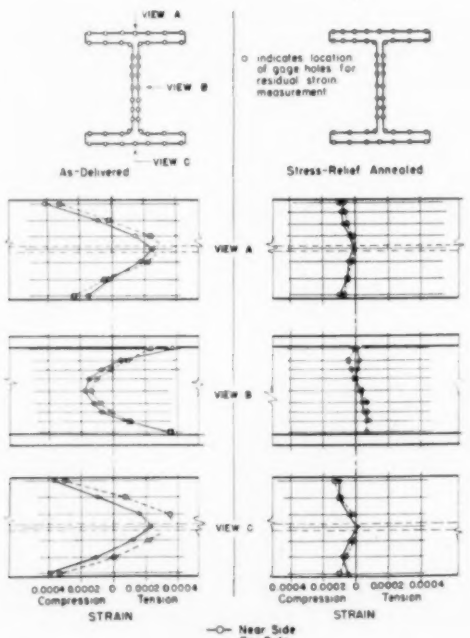


Fig. 26 Residual strains formed due to cooling after rolling of 8WF67 beam

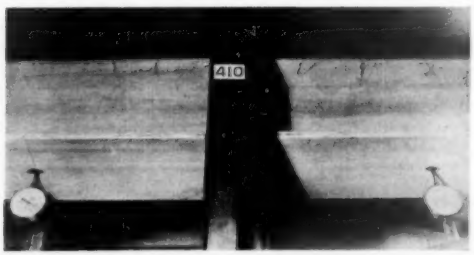


Fig. 27 Beam 4 showing yield zones at edge of compression (upper) flange

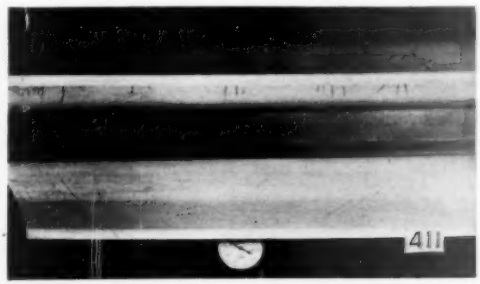


Fig. 28 Beam 4 showing yield zones in the tension (lower) flange formed subsequent to those in the compression flange

Thus, in bending, the edge of the compression flange should reach the yield stress first, and yield lines should be initiated there. On the other hand, the tension flange of the same section of the beam should reach the yield stress at a higher load and its yield zones should be initiated at the center of the flange. The yield zones will be initiated in both the tension and the compression flanges at loads that are theoretically less than the calculated initial yield load neglecting residual stress.

Figure 27 shows the first appearance of yield lines in the central span of B4 in the compression flange at the edge (load $W = 46$ kips.). Figure 28 shows the initial yield lines in the tension flange which started at the center of the span well after the development of lines in the compression flange ($W = 54$ kips.). When strain gages are mounted on the tension and compression flanges, the data show that the compression flange consistently reaches the yield stress first. The compression and tension yield points have the same average. (See Appendix A.)

In a recent inspection at a rolling mill it has been observed that no yield lines are formed due to cooling and prior to cold straightening of the member. A rough appearance of the mill scale at the junction of the web and flange is the only visible evidence of the plastic deformation which occurred there during the cooling cycle.

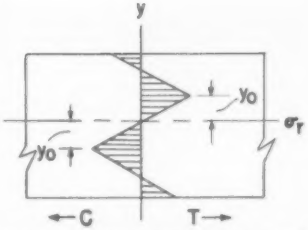


Fig. 29 Residual stress due to cold bending

(b) Residual Stress Due to Cold Bending or Cambering. Rolled sections are usually slightly bowed after rolling due to differential cooling rates. Cold bending is nearly always necessary to straighten the sections in the mill before delivery. Due to such bending beyond the yield strength, a pattern of residual stress is usually left in some parts of the rolled section which differs from the cooling residual stress pattern. A typical distribution of residual stress due to cold bending is shown in Fig. 29.* The magnitude of residual stress along the section will be:†

$$\sigma_{r1} = \sigma_y \left[\frac{y}{I} \left(\frac{I_p}{y_0} - Z_p \right) - \left(\frac{y - y_0}{y_0} \right) \right] \qquad (1)$$

$$\sigma_{r2} = \frac{\sigma_y y}{I} \left[\frac{I_p}{y_0} - Z_p \right] \qquad (2)$$

Subscripts 1 and 2 refer to the stress when y is greater than or less than y_0, respectively.

σ_y = yield point stress.
y = distance from the neutral axis.
I_p = moment of inertia of the plastic part of a section.
Z_p = plastic modulus of the plastic part of a section.
y_0 = distance to point of maximum penetration of yielding.
I = moment of inertia.

* In a discussion of residual stresses due to cold bending, Timoshenko[12] shows the distribution for a rectangular cross section deformed initially to its ultimate strength and then unloaded.

† The derivation is in Appendix B, equations 18 and 19.

Fig. 30 Examples of yield lines formed in flange of 8WF31 section due to cold bending after rolling. [The pattern has been accentuated by tracing the original (lines in ink)]

Fig. 31 An additional example of yield lines formed in the flange of a rolled shape due to cold bending

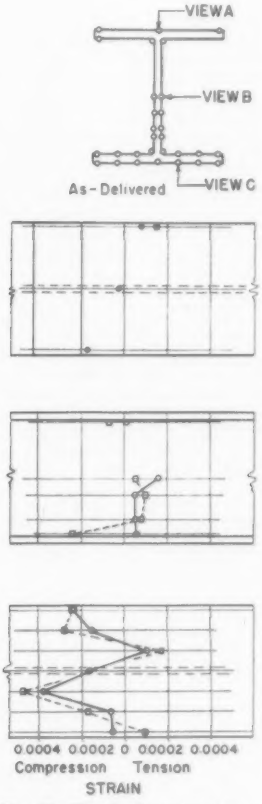


Fig. 32 Residual strains due to cold bending of 8WF40 beam

The maximum possible residual stress occurs when y_0 approaches zero ($M_0 = M_p$) and

$$(\sigma_r)_{max.} = \sigma_y. \qquad (3)$$

The existence of the pattern of residual stress shown in Fig. 29 will either raise or lower the initial yield strength of the section depending upon the direction of M_0 and the subsequently applied moment. The above expressions apply no matter about which axis the member is bent.

Figures 30 and 31 show Leuder's lines on the mill scale of a rolled section prior to test. Figure 30 with its diagonal lines shows a member which was probably cold bent ("gagged") in such a way that the flange shown was under tension. Thus yield lines, inclined at about 45 degrees to the beam axis and caused by tensile stress, are in evidence near the center of the flange where the residual stress due to cooling is in tension. Such is not the case in Fig. 31, the lines formed probably being due to cold bending about the weak axis. The similarity of these patterns of yield lines with those seen during the conduct of beam tests is confirmation that the yielding is due to cold bending.

The residual stress pattern measured across another WF section[1] is reproduced here in Fig. 32. The pattern is one which would be expected from cold bending.

The practice of cambering steel members undoubtedly leaves a similar stress pattern to that shown in Fig. 29. The initial yield strength of the member would be reduced by the residual stresses if load is applied in a direction opposite to that of the camber. Unfortunately, the load applied to a cambered section of a bridge or crane girder is usually in this "weaker" direction, so that a lowering of yield strength would be expected. This problem is now examined.

According to the A.I.S.C. Handbook, the maximum camber of a 21WF112 beam with a span of 25 ft. is 1 in. The maximum moment applied at every section of the beam during cambering is assumed to be a constant (beam under pure bending). Thus the curvature after cambering is also a constant, or, from Equation 15 of Appendix B,

$$\frac{d^2v}{dx^2} = -\frac{\sigma_y}{EI}\left[\frac{I_p}{y_0} - Z_p\right] = C_1 \quad (4)$$

$$\frac{dv}{dx} = C_1x + C_2$$

$$v = \frac{C_1x^2}{2} + C_2x + C_3 \qquad (5)$$

At $x = 0$, $v = 0$ and at $x = L$, $v = 0$. Thus, $C_3 = 0$, and $C_2 = -(C_1L/2)$. From Equation 5,

$$v = \frac{C_1}{2}[x^2 - Lx]$$

Now, at $x = L/2$, $v = 1$ in., the maximum camber; therefore, $C_1 = -(8/L^2)$. Substituting into Equation 4,

$$\frac{I_p}{y_0} - Z_p = +\frac{8EI}{L^2\sigma_y}$$

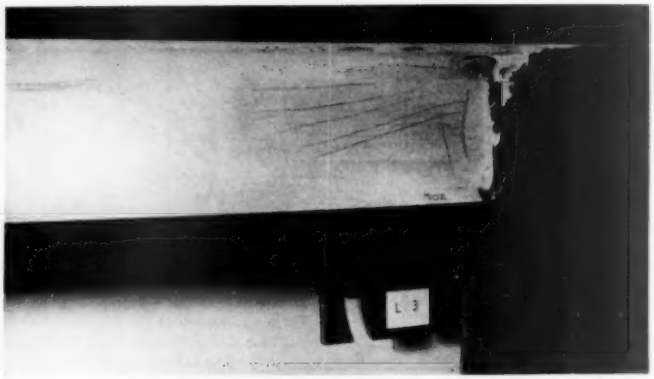


Fig. 33 Yield lines formed in web of B7 near load point

For the given problem, $L = 12 \times 25$ in., $I = 2621$ in.^{4} Assuming $E = 30 \times 10^3$ ksi., $\sigma_y = 33$ ksi., then

$$\frac{I_p}{y_0} - Z_p = 204 \text{ in.}^3$$

Solving the above equation, $y_0 = 5.5$ in. At the extreme fiber (Equation 21 of Appendix B)

$$\sigma_{r1} = \sigma_y\left[\frac{h}{2I}\left(\frac{I_p}{y_0} - Z_p\right) - \left(\frac{h - 2y_0}{2y_0}\right)\right]$$

and by substituting the known quantities,

$$\sigma_{r1} = -0.096\sigma_y$$

The negative sign signifies that the stress at the extreme fiber of the member is reversed after the load is removed. The flange loaded in tension during cambering would thus contain compression residual stresses at the extreme fiber. But this flange is normally the compression flange when used in a structure such as a bridge. Thus there is a reduction of yield strength of the member due to cambering of approximately 10%. There is likelihood of additional reduction due to the Bauschinger Effect, decreasing in the course of time due to aging.

However, cambering will remove other residual stresses in the flanges (welding, cooling and cold-straightening) which in themselves tend to reduce the initial yield load. Thus the exact magnitude of the reduction in yield strength due to cambering is expected to be quite variable. Theoretically, the ultimate strength would not be affected by the cambering process—only the yield strength.

(*c*) *Residual Stresses Due to Welding.* Residual stresses are developed in welded structures when dimension changes in heating and cooling cannot take place freely.[5] These are similar to those developed due to uneven cooling as discussed previously. The pattern of welding residual stress is usually very complicated because a large number of factors are involved such as the type of welds, the material, the welding procedure and the shape of the structure to be welded.

In the members tested in this program the welding involved was all in the vicinity of connections and load carriers. Thus the welding residual stresses would be localized and the pattern complex. The surface yield lines produced by the welding of load-carrying stiffeners were shown in Fig. 27 of Progress Report No. 1.[1]

In the event structural beams were built up by welding web plates to flange plates, a pattern of stresses should be obtained similar to that found due to cooling residual stresses described earlier. The mechanism for formation of these welding residual stresses is similar;[6] tensile stresses would be found at the junction of web and flange and compressive stresses at the flange edges. Thus the superposition of bending stresses on the member is expected to have a similar effect to that described earlier. This has been confirmed in the test of built-up connections described in Progress Report 4, Part I.[4] See, for example, Fig. 48 of that paper.

(*d*) *Stress Concentration.* The ordinary beam theory generally used in structural design will not predict precisely the stress distribution at the ends or support points of a structural member. Discontinuities introduced by welds, supports and changes of section occurring in a structural member cause local stress concentrations. Therefore, local yielding usually takes place in the structure well below the calculated initial yield load. As a result, early nonlinear behavior may be expected.

The three different support details shown in Table 1 were adopted in part to vary the magnitude of stress concentration. Although detail (*a*) involves the least amount of welding, the disturbance to the assumed shear distribution will probably be the greatest since the flange rests directly on the support. Cases (*b*) and (*c*), together with the load carriers, would provide more nearly the theoretically assumed shear distribution, but some deviation is still to be expected.

(2) *Test Results and Discussion*

The combined effects of welding residual stress and stress concentration cause local yielding at low loads at the supports. At portions of the member removed from the connections the cooling or cold-straightening residual stresses will cause a reduction in the load at which yielding first occurs and this yielding may extend over a greater length of beam than the part containing welding residual stress. The seriousness of residual stress in a member under flexure will depend in part on the resultant influence on the load-deformation relationship.

Local yielding at supports and load points generally changes the linear load-deflection relation into a nonlinear one, but the change is usually very small. On the other hand, when the load carrying stresses exceed the yield stress level, the change in the load-deflection relation is usually more drastic. Hardy Cross[8] has differentiated between "load-carrying stresses" and "participation stresses" and has emphasized the importance of evaluating the relative importance of the latter. Residual stresses due to welding at supports and the accompanying stress concentrations constitute a "participation stress" that is not serious provided it does not lead to low-temperature brittleness. On the other hand the participation stress due to cooling residual stress will be of greater importance since it is distributed all along the member. Thus in Fig. 15 where the beam is under pure bending, the addition of load-carrying and participation stresses would produce yielding all along the member at a lower load than predicted, resulting in a greater increase in deflection.

In most structures excessive deflections are objectionable. The justification for the present design methods that largely ignore residual and local stress concentration is the fact that the deflections of structures so designed are automatically limited. The criterion of strength of structures in reality always has been one of deflection rather than stress, so long as the stress level did not violate some other design condition. Consequently, the over-all influence of residual stress and stress concentration on the strength of a structure may be evaluated by considering the influence of these combined factors upon the deformations.

In the following paragraphs the data have been arranged under a number of headings which classify the means by which stress concentration and residual stress have been evaluated: i.e., (*a*) Local Plastic Flow, (*b*) Strain Measurements, (*c*) M-ϕ Measurements and (*d*) Deflection Measurements. Two additional sections have been included. In (*e*) dealing with welding residuals at supports, moment-load relations are studied; whereas, section (*f*) is a summary.

(*a*) *Local Plastic Flow.* Table 3 indicates loads at which yield lines first appeared at supports and at loading points as a result of stress concentration and welding residual stresses combined with load-carrying stresses. The location of yield lines is at the supports and load carriers, the lines usually forming in the web in a manner which indicates that yielding occurred due to combined bending moment and shear force. Figure 33 shows the location of the first observed yield lines in Test B7 and is typical of the first yield zones. Figures 34 and 35 show lines (traced in ink) at supports and load points where welding residual stress is probably an important factor. In this particular test (B4) these lines were formed at the load increment which followed that in which lines similar to those in Fig. 33 were formed.

Table 3 shows that local yielding occurred at loads as low as about 25% of the calculated initial yield load. B2 and B3 yield at the lowest loads, and one possible reason is that the reaction at the supports is transmitted directly through the flange to the stiffener (see Table 1). The stress concentration factor is undoubtedly greater than in the case of B4, B5 and B7. Also, since B2 and B3 were not spliced at the support, a greater amount of welding residual stress was probably present.

Fig. 34 Yield lines in compression flange of B4 at support

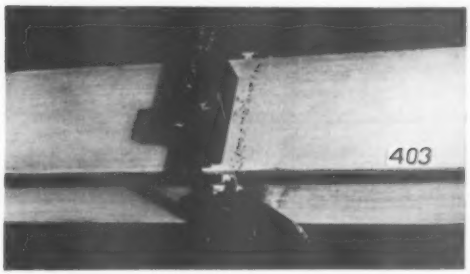


Fig. 35 Local yielding in compression flange of B4 at load point

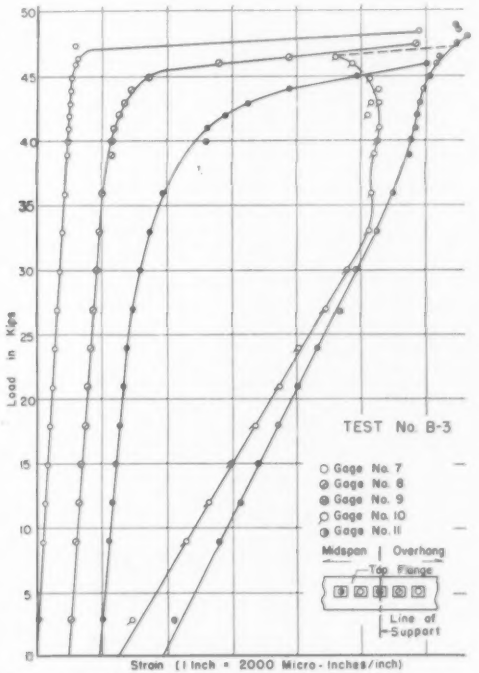


Fig. 36 Load-strain curves for gages mounted on the flange of B3 in the vicinity of a support

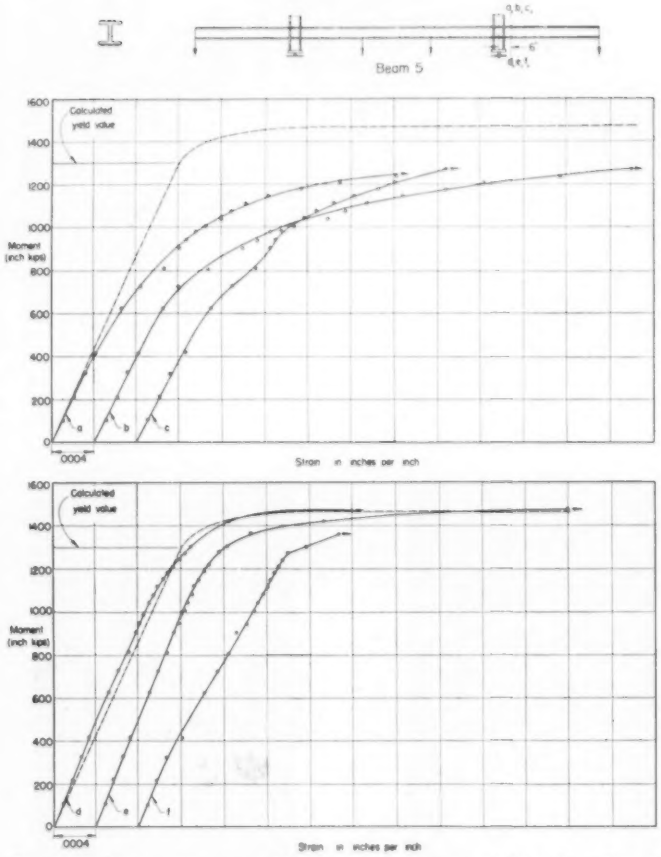


Fig. 37 Strain measurements of Beam 5 at a distance of 6 in. from line of support

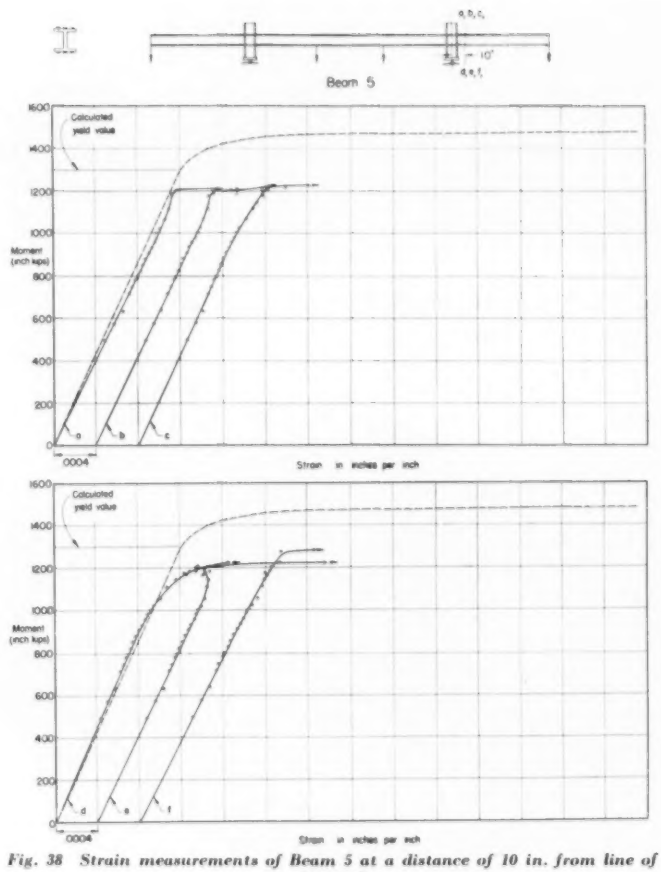


Fig. 38 Strain measurements of Beam 5 at a distance of 10 in. from line of support

The tests show that local yielding occurs at proportionately lower loads when the member is continuous over the support (B2 and B3) than when the support load is transmitted to the member by a splice plate (B4, B7) or a column stub (B5). In the latter cases local yielding occurs at about 45% of the calculated initial yield load.

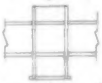
(*b*) *Strain Measurements.* The arrangement of SR-4 gages mounted on the flange of B3 in the vicinity of the support is shown in Fig. 4. These gages were installed to observe variations in strain due to stress concentration and residual stress. The data from the strain gages on the top flange over the support is plotted in Fig. 36. As determined by a deviation from a straight-line relationship, local yield was observed at a load of about $W = 24$ kips, while the calculated initial yield load for the beam is $W = 47.5$ kips. The earliest deviation is observed at gage 9 directly over the support point. The influence of the connection disappears very rapidly. (Compare gages 8 and 7 with 9.) The relative increase in strain at loads below 30 kips, for gages 10 and 11 is possibly due to the fact that the gages are located in a region of high shear and since the web does not carry its proportionate share of the moment, the flanges carry increased strain.

The data from strain gages mounted on B5 also indicate a nonlinear behavior at low loads close to the support. Figures 37, 38 and 39 show that the outer fiber of the beam section 2 in. from the juncture with the columns started to yield at a much lower moment than the sections which were 6 in. from each column. At 16 in. distance from the column flange (Fig. 39) the discrepancy between test and theory is still less although local deviations still exist.

Rosette gages mounted on the web of B4 make possible the comparison of experimental with the theoretically predicted maximum strain distribution on the web of the beam near a support and a load point. These relationships are shown in Fig. 40. The early portion of the average experimental curves are very close to the theoretical ones. However, local yielding caused deviation between experimental and theoretical curves as the loads were increased. The theoretical moment shear strain curves in Fig. 40 were computed on the basis of shear and flexure beam formulas.

(*c*) *M-ϕ Measurements at Beam Center.* The strain data presented in the previous section were all collected from gages located at the supports or load points and are thus sensitive to stress concentrations and welding residual stresses. Since these two factors are not present in the center of the beam span, the influence of the cooling residual stresses may be observed from M-ϕ curves previously presented, Figs. 8–11 and 24. Comparing

Table 3—Observed First Yield Lines

BEAM	CONNECTION DETAIL	FIRST APPEARANCE OF YIELD LINES W_L (kips)	INITIAL YIELD LOAD (calculated) W_Y (kips)	$\frac{W_L}{W_Y}$ (%)
B 2		9.0	35.5	25.4
B 3		10.5	47.5	22.2
B 4		15.0	35.5	42.3
B 5		18.0	35.5	50.6
B 7		18.0	43.8	41.6

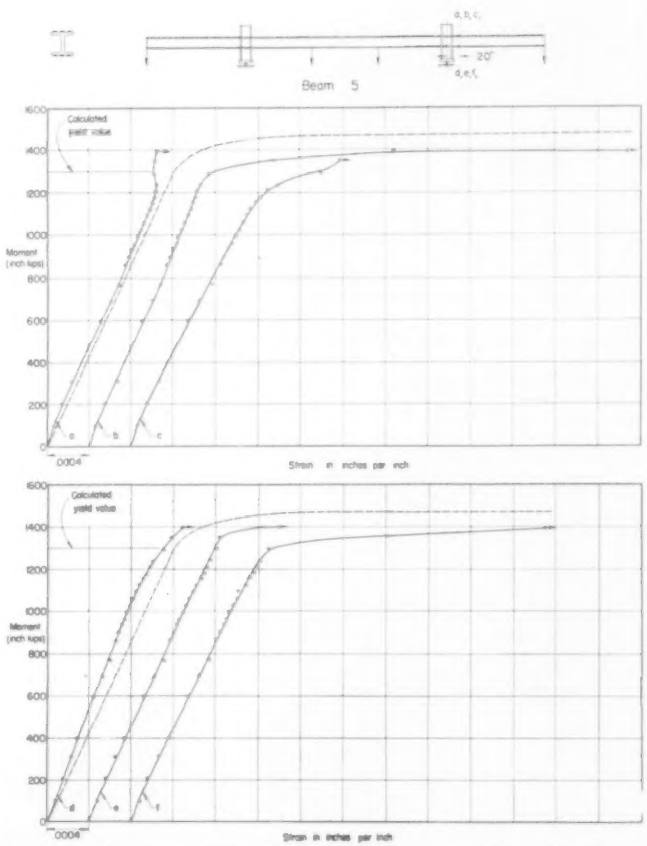


Fig. 39 Strain measurements of Beam 5 at a distance of 20 in. from line of support

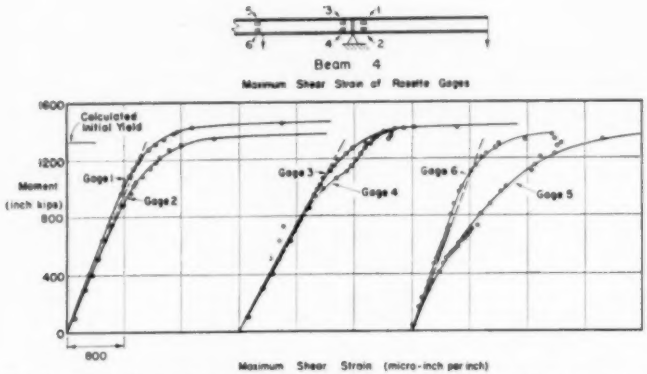


Fig. 40 Theoretical and experimental maximum shear strains at three cross sections of Beam 4

the experimental moment carried at the predicted initial yield rotation, ϕ_y, with the theoretical value, the per cent reduction of moment due to cooling residual stress is shown in Table 4. The reduction ranges from about 6 to 11%. Examination of Figs. 8–11 and 24 show that the per cent increase in ϕ at the calculated initial yield moment is greater than the above percentage reductions in moment.

Table 4—The Reduction in Yield Strength Due to Cooling Residual Stresses

Beam	*Calculated initial yield moment, in.-kips.*	*Observed moment at calculated initial yield rotation, ϕ_y, in.-kips.*	*% Reduction of moment, %*
B2	1325	1180	10.9
B3	1325	1240	6.4
B4	1325	1190	10.2
B5	1325	1200	9.5
B7	1636	1510	7.5

(*d*) *Deflection Measurements.* Nonlinear behavior due to local yielding at loads lower than predicted is reflected in the load deflection curves.

The values of the initial yield load and corresponding deflections of the beams have been calculated assuming elastic behavior and are tabulated with results of tests in Table 5. It indicates the overall influence of residual stress and stress concentration upon yield strength. Two methods of comparison have been used to specify "yield strength." Measured and theoretical deflections are compared at the calculated initial yield load (Column 4) and measured and theoretical loads are compared at the calculated initial yield deflection (Column 7). Figure 41 demonstrates the method by which the data in Table 5 were obtained, the increment of deflection at W_y and the reduction of strength at δ_y being indicated.

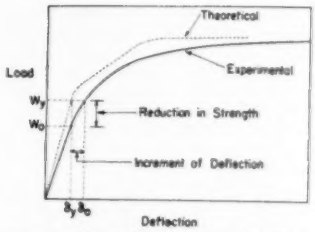


Fig. 41 Hypothetical load-deflection curve showing method for determining the yield strength

The experimental load-deflection curves are shown in Figs. 49, 50 and 51.

The tests show that the beams reached the calculated deflections at lower loads than predicted (ranging from 10 to 25%) and that at the calculated initial yield load the deflections were greater than predicted (ranging from 13 to 88%).

The effects of local yielding on the deflection of structures also depends on the type of loading (or restraint) on them. Beam B3 was tested to simulate a single-span frame. The ends of the two overhanging beams were maintained at the same elevations as the two supports. The loading and simulated frame are shown in Fig. 42. In the elastic range the moment diagram of the beam will then be such that the moments at the supports and the center are equal. At the calculated initial yield load (W = 47.5 kips.) moments should be the same at the center and supports and equal to 1325 in.-kips. The corresponding calculated maximum deflection will be 0.79 in. At the same load the deflection observed in Test B3 was 88% greater (Table 5).

The percentage increment of deflection at the calculated initial yield load for the rest of beams in Table 5 is smaller. In

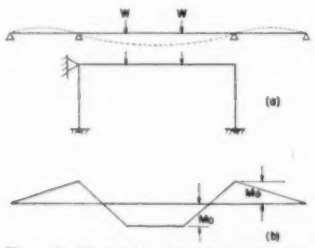


Fig. 42 Test B3. Loading arrangement, simulated frame and distribution of moment

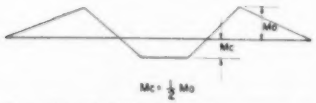


Fig. 43 Distribution of moment in Beams 2, 4, 5 and 7

Table 5—Yield Strength of Continuous Beams

BEAM	DEFLECTION AT INITIAL YIELD (computed) δ_y	OBSERVED DEFLECTION AT INITIAL YIELD δ_o	% INCREMENT OF DEFLECTION	INITIAL YIELD LOAD (computed) W_y	OBSERVED LOAD AT δ_y W_o	% REDUCTION IN LOAD
	(in.)	(in.)		(kips)	(kips)	
B2	.30	.42	40.0	35.5	27.0	23.9
B3	.79	1.47	88.0	47.5	40.5	14.7
B4	.30	.41	36.6	35.5	28.0	21.1
B5	.30	.34	13.3	35.5	32.0	9.9
B7	.18	.24	35.8	43.8	33.0	24.1

tests 2, 4, 5 and 7 "fixed-ended" conditions were simulated at the supports. Figure 43 shows the corresponding moment diagram. In this case, the two ends of the central section of the beam will start to yield before the theoretical initial yield load of the beam is reached. But the theoretical magnitude of the moment in the central section is only one half that of the support when the beam is perfectly elastic. Therefore, the central section should not start to yield at all until the load on the beam has increased by a certain amount. During this period the end sections will continue to deform, and before the central section yields the support moments will approach the plastic hinge moments. Thus, the effects of residual stress and stress concentration at the ends will largely be eliminated. The deflection of the beam at the initial yield load will still be higher than the calculated value, but the ratio of increasing deflection will not be as great as in the case of B3.

Comparing B2, B4 and B5 (Table 5), the only variable is the connection detail. The sequence of decreasing increment of deflection is accounted for, in part, by the increased restraint against shear deformation provided by the increased stiffness of the connections.

Table 5 also shows that B4 and B7—identical except for shape of cross section—behaved in similar fashion in the region of their respective initial yield loads. Thus, from these tests there is no significant influence of shape of section on the yield strength. It is expected that this may not be true in the plastic range.

In some structures deflection is critical. In others, large deformations may be tolerated. The above discussion and the comparisons made in Table 5 concern the region of the initial yield load. This was done because the statistical nature of the factor of safety does not eliminate the possibility of loads exceeding the working load. However, when deflections are examined in routine procedures, the limitation is usually based on the deflection at working loads. Table 6 presents a comparison similar to that contained in Table 5 except at the working load. Deflections are larger than predicted ranging from zero to about 18%. If the deflection were to be limited by the A.I.S.C. specification it would be necessary to reduce the theoretical working load for B3 from 28.8 to 28.1 kips. Due to residual stress and stress concentration, Table 6 indicates a further reduction of about 8%.

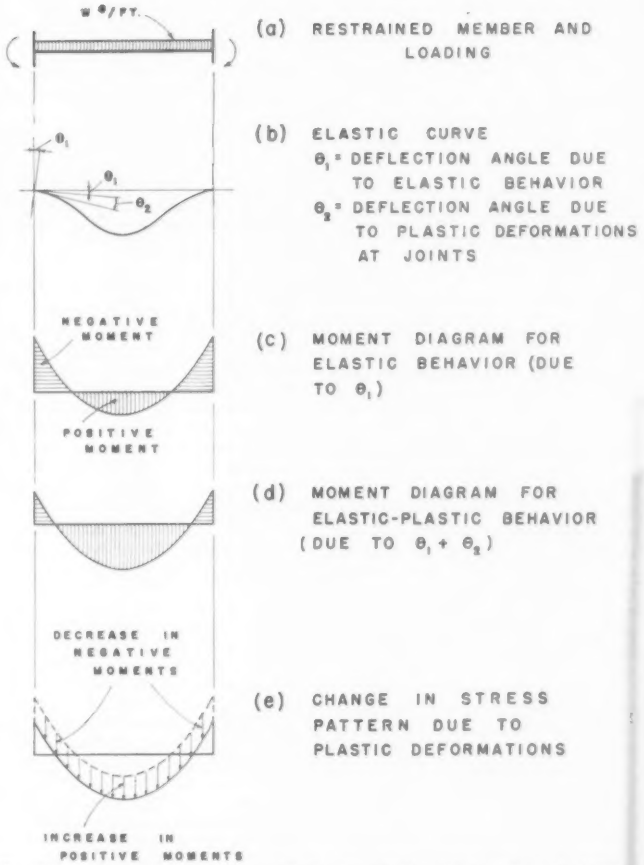

w #/FT.
(a) RESTRAINED MEMBER AND LOADING
θ_1
θ_1
θ_2
(b) ELASTIC CURVE
θ_1 = DEFLECTION ANGLE DUE TO ELASTIC BEHAVIOR
θ_2 = DEFLECTION ANGLE DUE TO PLASTIC DEFORMATIONS AT JOINTS
NEGATIVE MOMENT
POSITIVE MOMENT
(c) MOMENT DIAGRAM FOR ELASTIC BEHAVIOR (DUE TO θ_1)
(d) MOMENT DIAGRAM FOR ELASTIC-PLASTIC BEHAVIOR (DUE TO $\theta_1 + \theta_2$)
DECREASE IN NEGATIVE MOMENTS
(e) CHANGE IN STRESS PATTERN DUE TO PLASTIC DEFORMATIONS
INCREASE IN POSITIVE MOMENTS

Fig. 44 Redistribution of moment due to plastic deformation—Amirikian[7]

Table 6—The Strength of Continuous Beams at Working Loads

	Beams limited by load			
Beam	*Working load,* kips.*	*Calculated deflection at working load, in.*	*Observed deflection at working load, in.*	*Increment of deflection, %*
B2	21.5	0.18	0.21	16.7
B3	28.8	0.48	0.52	8.3
B4	21.5	0.18	0.18	0
B5	21.5	0.18	0.21	16.7
B7	26.5	0.11	0.13	18.2

	Beams limited by deflection			
		Load at limit deflection		
Beam	*Limit deflection,† in.*	*Theoretical, kips.*	*Experimental, kips.*	*Reduction in load, %*
B2	0.47	...	...	...
B3	0.47	28.1	25.9	7.8
B4	0.47	...	...	..
B5	0.47	...	...	..
B7	0.47	...	...	..

* Theoretical elastic limit load divided by 1.65.
† A.I.S.C. Specification: $^1/_{360}$ multiplied by the span length in inches.

(e) *Welding Residual Stress at Supports.* The effect of welding residual stress at supports has been considered by Amirikian.[7] The example is reproduced in Fig. 44 for illustration. The "decrease" shown in (e) is a decrease in moment at the support as compared to that which would be theoretically computed and does not represent an actual reduction in moment under increasing loads. For example, a variation in the experimental moment-curvature relationship such as that shown by the solid line in Fig. 45 indicates, for a given end rotation ϕ_1, that the connection will carry only a moment M_1 instead of the predicted moment M_p.

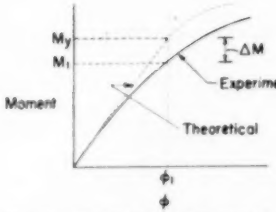


Fig. 45 Hypothetical decrease in moment capacity at a joint for a given unit rotation

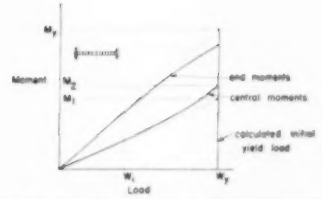


Fig. 46 Hypothetical moment-load characteristics of beam with welding effects at joints

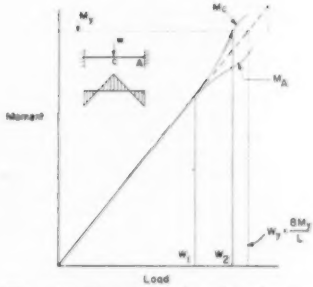


Fig. 48 Hypothetical redistribution of moment due to yielding at supports only

Quoting from Reference 7, "Under dead loading as well as under initial applied loading, the changes of stress in members of a frame due to plastic yielding at the joints may be of such magnitude as to require a revision of our present methods of analysis of continuous structures." For simplicity, assume that the ends of the beam are built in. In Fig. 46 the moments at the central section and at the two ends of the beam are plotted against the load. The dotted lines represent the elastic case where end moments have a value equal to 50% of the central moment. Assuming typical inelastic behavior commencing at a load W_1, the center section is called upon to carry a greater moment than predicted. When the load reaches W_y the central moment is M_2 instead of $M_1 = {}^1/_2 M_y$.

When the results of the continuous beam tests are presented in this manner (Fig. 47) they do not show the redistribution of moment expected according to the previous discussion. (The dotted lines represent theoretical curves which have been determined by a numerical integration process.*) However this does not mean that there was no local plastic yielding at the supports below the calculated yield load. In fact it has already been demonstrated that this did occur. The redistribution of moments shown in Fig. 46 is under the assumption that the central part of the beam does not yield locally. In the tested beams local yielding occurred both at the supports and in the central section near the loading point. Examples were given in Figs. 33, 34 and 35. Therefore, the curves in Fig. 47 do not show significant redistribution of end and central moments at loads below their calculated initial yield strength because the effects of local yielding at supports are offset by local yielding at load points.

A more critical case, theoretically, is that of the fixed-ended beam with central concentrated load. In Fig. 48, if at load W_1 the connection yields, then the center is called upon to carry greater moment than predicted. When load W_2 is reached the central section will yield at a load which is less than W_y. On the other hand if local yielding only occurs at the central section of the beam and the connections remain perfectly elastic, the moment will be increased at the supports. B3, although of different loading and end restraint, also has equal moments at the center and the support and its behavior shown in Fig. 47 indicates that the distribution of moment was not affected substantially.

These tests show that the welding of a stiffener between flanges causes local yielding at lower bending moments and is thus of more significance than yielding in butt welds to splice plates and columns. In B4, for example, flange yielding occurred over the support (Fig. 34) and the load point (Fig. 35) at the same time and at a load of about 18 kips. However the moment at the support is twice as great as that at the center, indicating a more serious condition created by the load carrier and intermediate stiffener. In Fig. 47 no deviation in the moment-load relation from theoretical values is seen at a load of 18 kips. (In Fig. 49 B4 does indicate an increase in deflection.) Thus the effects of yielding at supports and load points offset one another. This is also true of B5 and B7 where the details are similar. The slight discrepancy in B2 and B3 (Fig. 47) is observed because the support detail is an intermediate stiffener and is similar in its welding effects to the load carrier (Table 1). As predicted by Amirikian, a change in moment-distribution occurs, but the deviation is of small magnitude and does not exceed about 8% at the theoretical initial yield load.

Local yielding did increase the deflections of the beams by larger increments, percentagewise, as was shown in Table 5. The load-deflection curves of the beams tested are shown in Figs. 49, 50 and 51. The theoretical curves are indicated by the dashed lines in each case. A portion of the improved behavior of B4 over B2 and B5 over B4 is due to the increased

* Similar curves have been used by Horne[12] in a paper which describes (on a theoretical basis) the influence of strain hardening on the ultimate strength.

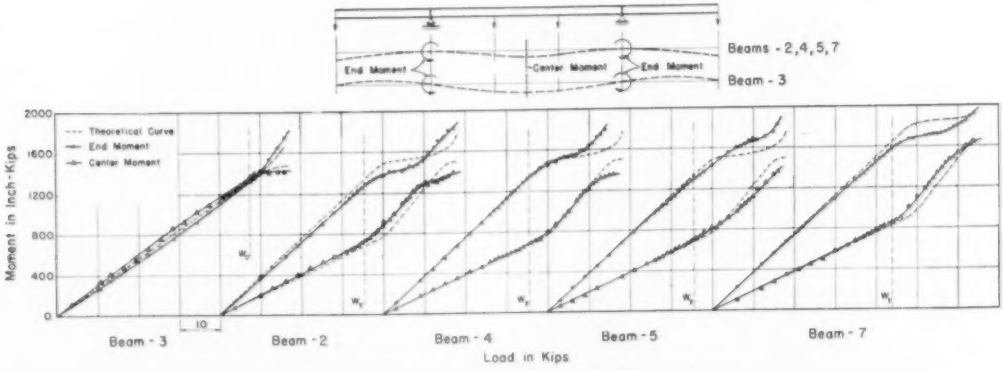


Fig. 47 Moment-load relationships for continuous beams

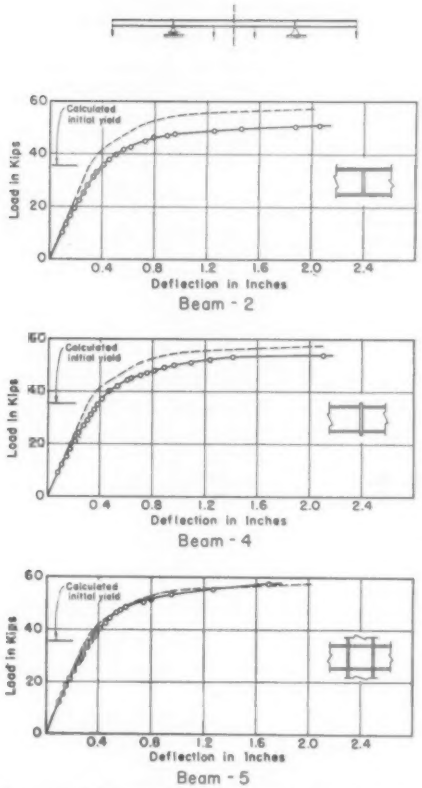


Fig. 49 Experimental and theoretical load-deflection curves for continuous beams 2, 4 and 5. Deflection measured at center line

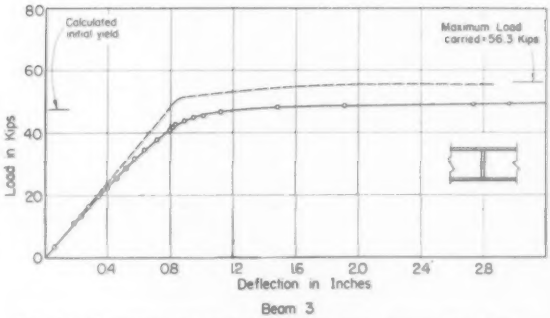


Fig. 50 Experimental and theoretical load-center line deflection curves for B3 (8W F40)

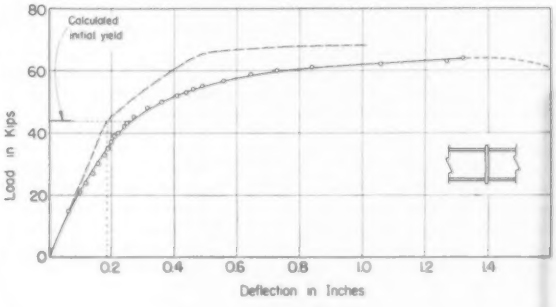


Fig. 51 Experimental and theoretical load-center line deflection curves for B7 (14W F30)

stiffness of connections which has been mentioned earlier. Yielding of the web due to shear force occurred on the two sections that extend between the supports and third point loads.

Amirikian[7] has emphasized the importance of welding residual stresses at beam connections. Actually, as observed from the experiments, the presence of cooling residual stress is also an important factor and in some cases will have a greater effect. In Fig. 52 the early part of the load deflection curve of Beam B3 is plotted to a larger scale. Yield lines just appeared in the web of the beam in regions close to the supports and loading points at a load of $W = 10.5$ kips. It is evident that the deflection measurement was scarcely sensitive to the change at this load. As the load increased the local yield lines increased in number, but they were confined to these very small areas near the supports and loading points.

At a load $W = 40.5$ kips., yield lines suddenly developed in the compression flange along the whole central portion of the beam between the loading points (Fig. 16). At the same time the yield lines in the compression flange near the supports had spread to a much larger area than the local yield lines previously developed.

Apparently local yielding due to welding residual stresses and stress concentration commenced at a load which was about 20% of the calculated initial yield load. The bending stresses in the compression flange near the supports and in the central portion of the beam superimposed with the compression residual stresses due to cooling reached the yield point at a load between 37.5 and 40.5 kips. Figure 52 shows that the deflection increment due to local yielding below a load of 37.5 kips. is very small. On the other hand, deflections started to increase drastically above the load at which the cooling residual stresses came into effect. Therefore, it seems that the cooling residual stresses are of more importance in causing an increase in deflections than are welding residual stresses and stress concentration at the connections.

(*f*) *Summary.* To summarize the above discussions the yield strength of structures is affected by factors such as stress concentration and residual stress. The presence of these factors will increase the deflection of the structure. Welding residual stresses and stress concentration at the joints of continuous beams have rather small effects on the deflections when compared with cooling residual stresses. However, it is expected that the effects of welding residual stresses will be more pronounced if the welds are

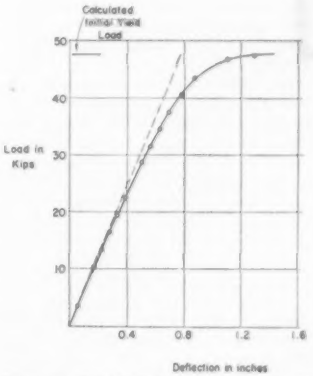


Fig. 52 Load-deflection relation of B3 in the region below the calculated initial yield load

applied all along the structural member. This is the case when an I section is made up of plate material or in large built-up connections. The cooling residual stresses are present no matter whether riveted, bolted or welded construction is used.

The magnitude of redistribution of moment, and hence stress, due to local yielding is of small magnitude and does not compare to the percentage increase in deflection due to the same factors.

If it is considered that the increase in deflections (or permanent set under load) due to stress concentration and residual stress is critical then it appears that the present design theory of a permissible working stress based on the initial yield would require modification. Such a modification could be an increase in the factor of safety to cover the effects of cooling residual stress.

Since safe structures are designed according to presently accepted specifications, it is probable that the factor of safety already covers the possible reduction of strength of steel structures due to residual stress. However, it appears that the percentage reduction due to this factor has not generally been realized since the term "Presence of Residual Stress and Stress Concentration" is not usually found in lists of possible unavoidable errors in design.[3]

(V) ULTIMATE STRENGTH OF CONTINUOUS BEAMS

In the structures tested, which had the ability to deform plastically, there is no particular significance in the initial yield load.* Yielding due to residual stresses and stress concentrations combined with load-carrying stress actually occurred at loads well below those predicted according to conventional theory. The accelerated increase in deflections commenced either at loads lower than or greater than the initial yield load. For such structures, then, although designs based upon it have been successful, the initial yield load is not a particularly rational basis for design. Deflection seems to be the more logical criterion and this concept has been examined elsewhere.[3]

The effects of residual stresses or stress concentrations at a beam section are theoretically eliminated after the section has been subjected to a certain amount of plastic straining. From test results it has been observed that the plastic hinge moments of the beam sections agree with the calculated values after yielding has completely penetrated into the web of the section. Since the plastic hinge moment is not reduced by residual stress and stress concentration, it is not likely that the ultimate strength of a structure is affected unless inelastic local buckling is introduced.

* The possibility of structural brittleness must be avoided by the use of proper materials, good design and correct fabrication practices.

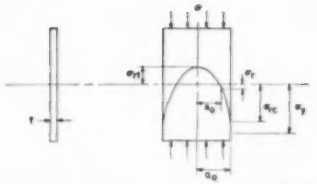


Fig. 53 Plate containing residual stress and subjected to a uniform compressive stress at the ends

The subject of local buckling will be discussed in detail in a separate report. A paper on factors which influence the ultimate strength of continuous beams is in preparation. In this report attention is restricted to the yield strength of the beams tested.

(VI) THE INFLUENCE OF RESIDUAL STRESS ON THE BUCKLING STRENGTH OF STRUCTURAL MEMBERS

Residual stress reduces the yield strength of a beam or frame; it also affects the buckling strength of structural steel members. Consider the example of a steel plate which has cooling residual stresses uniformly distributed along the member with the symmetrical pattern at each cross section as shown in Fig. 53.† Under the compression load shown, the edges of the plate will start to yield as soon as the average stress σ reaches the value

$$\sigma = \sigma_y - \sigma_{rc}$$

where σ is the applied stress, σ_y, the lower yield point stress and σ_{rc} the compression residual stress at the edges.

If the yielded parts of the plate are considered to be perfectly plastic,* the bending stiffness of those portions will reduce to zero. When the tangent modulus concept† for buckling is used, the buckling strength of the compression member will be equivalent to that of a compression member considering only the elastic part.

If the residual stress pattern is known, the buckling strength of the plate of Fig. 53 about its weak axis can be found in terms of the tangent modulus of its average stress-strain diagram considering the residual stresses in it. Consider for example that uniform compression is applied to the ends of the specimen. In Fig. 54 is shown the resultant combination of residual and load-carrying stress. The material is assumed to have a linear stress-strain diagram. Also, the load-carrying strain is assumed constant over the whole cross section. Let

* The stress-strain diagram is idealized to consist of two straight lines with slopes E and zero.

† A symmetrical distribution pattern is typical for residual stresses due to cooling. The problem of unsymmetrical distribution of residual stress is not considered here.

A = one half of the total cross-sectional area of the plate.
$A = a_0 t$.
A_e = one half of the elastic area.
$A_e = t x_0$.
x_0 = one half the width of the elastic portion.
σ_r = residual stress function.
σ = average stress on the cross section of the plate.

When $\sigma_{rc} + \sigma$ exceeds σ_y, part will be elastic and part plastic. The total force at the cross section must balance the applied force, $\sigma \times A$. Prior to loading, however, the net force was zero since the residual stresses were in equilibrium. Thus the net force after loading is made up of an increment of force in the plastic part (x between x_0 and a_0, stress magnitude $c-d$) and an increment of force in the elastic part (x between zero and x_0, stress magnitude $a-b$). Since

$$c - d = \sigma_y - \sigma_r$$

and

$$a - b = \sigma_y - |\sigma_r|_0$$

then

$$\sigma \times A = \int_{x_0}^{a_0} t(\sigma_y - \sigma_r)\, dx + t x_0(\sigma_y - |\sigma_r|_{x_0}) \qquad (0 < x_0 < a_0) \quad (6)$$

σ_r in the above equation can be determined by measuring or in some cases it can be solved as an analytic function.

x_0 can be found by solving Equation 6. Then

$$E_t = \frac{d\sigma}{d\epsilon} = E\frac{A_e}{A} = E\left(\frac{x_0}{a_0}\right)$$

This value of E_t may be used to predict the buckling strength of the compression member according to the concept of tangent modulus theory from the equation,

$$P_t = \pi^2 \frac{E_t I}{L^2} \qquad (7)$$

For purposes of illustration of the possible effect of residual stress upon the buckling strength of structural members, a typical distribution for the flanges of wide-flange shapes is selected in which the pattern is parabolic in shape with the compression residual stress equal to 20

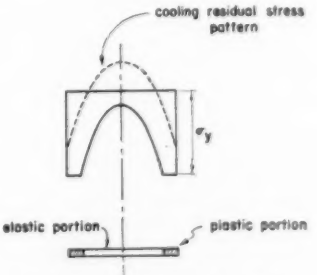


Fig. 54 Resultant stress-distribution upon application of external force sufficient to cause a certain amount of yielding

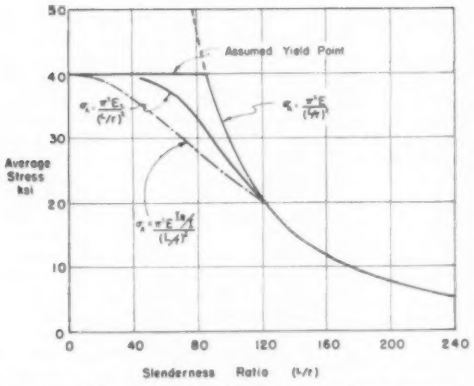


Fig. 55 Effect of residual stress on column strength

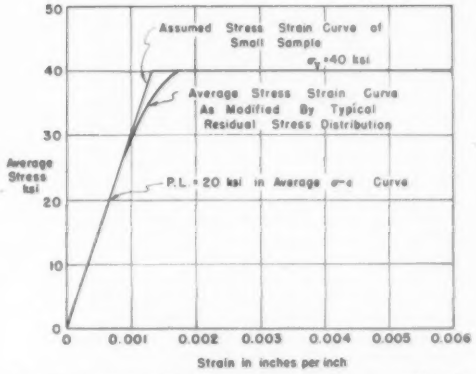


Fig. 56 Stress-strain diagram for steel as modified by residual stress

ksi. and the maximum tensile value in the flange center equal to 10 ksi.; (i.e., in Fig. 53 $\sigma_{rc} = 20$ ksi. and $\sigma_{rt} = 10$ ksi.). The residual stress function, σ_r, for a 10-in-wide flange is then given by,

$$\sigma_r = 10 - 1.2x^2,$$

positive when in tension, the distance x being measured from the center line of the flange. The material is assumed to have a yield point stress of 40 ksi. By substituting the above formula into Equation 6 an expression for z_0 is obtained, enabling a direct calculation to be made of E_t for various assumed values of σ. The column curve may then be drawn and this is shown in Fig. 55. The average critical stress is plotted against slenderness ratio. The Euler relationship is shown. The calculation just described gives the solid curve.

$$\sigma_A = \frac{\pi^2 E_t}{(L/r)^2}$$

The dashed curve is described later.

The average stress-strain diagram could be obtained by determining strain values to correspond with the above assumed stress values from the relation

$$\epsilon = \frac{\sigma_y - |\sigma_r|_{z_0}}{E} \qquad (8)$$

The resulting average stress-strain curve as modified by the assumed residual stress pattern is shown in Fig. 56.

For sections of different cross-sectional shapes the buckling strength can be found in a similar way. Assume that the distribution of residual stress in a WF shape is similar to that shown in Fig. 26. When the average applied stress reaches a certain magnitude, portions of the cross section will yield as shown in Fig. 57. The buckling strength of it can be calculated by considering only the elastic part and results in the expression

$$P_{cr} = \frac{\pi^2 E I_e}{L^2} \qquad (9)$$

where I_e is the moment of inertia of the portion which remains elastic.

In the case of the rectangular section bent about the weak axis

$$E_t I = E I_e.$$

This is also very nearly true for the WF section bent about its strong axis since the web contributes only a small portion to the moment of inertia. However for the rectangular section bent about its strong axis and for the I-section bent about its weak axis the term EI_e will be considerably less than $E_t I$. Thus the buckling strength will be reduced over that value predicted by the tangent modulus concept alone. The average critical stress will be given by the equation,

$$\sigma_A = \frac{\pi^2 E_t I_e}{(L/r)^2}$$

For the same pattern and magnitude of residual stress as used in the previous illustrative example, the column curve has been computed for flexure about the strong axis of a rectangular element. The result is plotted as the dashed line in Fig. 55.

The magnitude of reduction in carrying capacity of columns containing residual stress is thus also dependent upon the axis about which the member is free to rotate. For rectangular cross sections, referring to Fig. 55, greater reductions occur for flexure about the strong axis. The curves for a WF shape with 10-in. flange width will be similar except that the upper curve is for flexure about the strong axis (x-x), the lower (dashed) curve resulting when the column is free to rotate about its minor (y-y) axis.

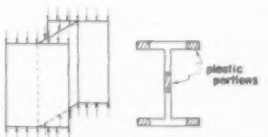


Fig. 57 Short compression specimen of WF shape at a load sufficient to cause yielding due to residual stress

While it was recognized by the authors some time ago that the buckling strength of a WF-shaped member would be that of the part remaining elastic, these ideas were not generally circulated nor were they extended. The problem has been discussed in a dissertation[21] by one of the authors. According to prepublication abstract, Osgood* has recently obtained a "general expression for the buckling load of a column containing residual stresses assumed to be the same at every cross section and so distributed over the cross section that the Engesser-Shanley theory may be applied."

When residual stresses are not the same at all sections of the compressed member, the problem becomes one of the buckling strength of a member of varying cross-sectional areas. At local sections which are cold-bent or which contain welding residual stresses, it can be considered that the dimension is reduced at those sections due to yielding caused by local residual stresses. The effect will be generally smaller than that of the cooling residual stresses which are distributed all along the member.

Figure 55 shows the large reduction in column strength that may be expected from the rather common pattern of residual stress shown in Fig. 53. This implies, of course, that the material behaves as assumed in the theory. Actually as was discussed earlier, yielding is not uniformly distributed along the member, but yield zones penetrate into the member at intervals along it. Thus the effective stress-strain diagram will be something different from that shown in Fig. 56, thus modifying the column curve of 55. Further experimental work is needed here and a part of this is being carried on in current investigations.

An important question to be answered is the following: Can a satisfactory column-strength curve for heavy steel columns be based on small samples re-

* Osgood, W. R., "Residual Stresses in Columns." Presented at the First U. S. National Congress of Applied Mechanics, Chicago, Ill., 1951.

moved from flange and web if the cutting out of the small samples relieves the residual stresses in the columns? The evidence from the above discussion indicates that a satisfactory column curve for steel *cannot* be obtained from tests of small coupons and this trend has been confirmed experimentally by pilot tests on complete cross sections of WF steel specimens.

The influence of residual stress on the buckling strength of a compression member is seen to be significant. Since residual stress causes a reduction in yield strength, it may also be a factor in local buckling. Since flange elements eventually buckle locally in the plastic range, yielding at lower loads than predicted may also reduce the local buckling strength of a bending member. This factor has not been examined in these tests and would probably require studies of annealed and unannealed specimens.

It is probable that column design formulas have included empirically the reduction in carrying capacity due to residual stress, although the percentage reduction due to this factor has not generally been appreciated. This indicates once more that experience and prior satisfactory performance is now, as it has always been, the important factor in structural design.

(VII) CONCLUSIONS

1. While this report emphasizes the influence of residual stresses and stress concentration upon the yield strength of steel beams, it is not to be assumed that the plastic range and ultimate strength are of any lesser importance. Since there is not space here to treat the whole problem, and since most engineers are concerned with design based upon the initial yield load, it was considered that the influence of the various factors on the yield strength should be presented first.

2. According to experimental data, the assumption of a uniform distribution of plastic strain in a bending member is far from the actual picture. Making use of this assumption, the M-ϕ relation of a bending section gives better agreement with test results for annealed specimens than for as-delivered specimens. (The annealed tests were carried out in a previous program.)

3. There is a difference in the behavior of as-delivered and of annealed specimens over and above a difference in material properties. The process of initiation and propagation of plastic zones in a bending member is affected by residual stress and stress concentration which indirectly affect the M-ϕ relation. As-delivered specimens consistently show a reduction of about 10% in moment capacity in the early part of the plastic range. However, when yielding later penetrates to the neutral axis the moment capacity approaches the value predicted on the basis of coupon tests.

4. Due to residual stress and stress concentration local yielding may occur in a structure at a load very much lower than usually predicted by theory. In these tests such yielding occurred at loads as low as about 20% of the predicted initial yield load.

5. The yield strength of a structure is reduced by the presence of residual stress and stress concentration no matter whether load or deflection is used as the criterion. In these tests the reduction of load was as much as 24% and the increase in deflection at the initial yield load ranged from 13 to 88%.

6. Concerning the increase of deflection in a structure, cooling residual stress is a more important factor than welding residual stress or stress concentration.

7. There was no significant influence of shape of cross section on the yield strength.

8. The initial yield strength of a cold-straightened beam may be raised or lowered depending on the direction of cold-straightening and of load application. Cambered beams would have their yield strengths reduced due to the necessary cold bending process. Expressions for determining the residual stress distribu tion are presented.

9. The magnitude of redistribution of moment due to local yielding at welded connections is of small magnitude and does not compare to the percentage increase in deflection due to the same factor.

10. The stress concentration and residual stress involved in the welding of stiffeners between flanges of a member causes local yielding at lower bending moments and is thus of more significance than yielding in butt welds to splice plates and columns.

11. The buckling strength of a member is reduced by residual stresses, this factor being of major importance for structural steel columns in the intermediate slenderness range.

12. The evidence indicates that a satisfactory column curve for steel cannot be obtained from tests of small coupons.

13. For use in predicting the strength of a column of rectangular cross section containing residual stress, a method for determining the tangent modulus is suggested. A general expression is presented which integrates the effective stress distribution across the member.

14. For members of different cross-sectional shapes than rectangular and which contain residual stress, the buckling strength is theoretically reduced over that predicted by the tangent modulus concept alone. The buckling strength under these conditions would be that of the part remaining elastic. Additional studies, including experiments, are needed to see if these additional reductions actually occur.

15. The specimens tested in this program were all rolled shapes. While it is expected that the residual stress patterns will be similar in members which are built up by welding web plates to flange plates, there will probably be considerable variation from member to member and along the same member. Also the influence of residual stress due to longitudinal welds may be different. An investigation along these lines would be worth while.

16. It is probable that the factor of safety for steel members has always included the reduction in carrying capacity due to residual stress and stress concentration. However, the percentage reduction due to this factor has not generally been appreciated. If the increase of deflection is considered critical then a change in design procedure that would allow greater working loads must be approached with extreme caution. However, in structures in which deflection is not a critical item from a statistical point of view, then there is nothing in the results of these tests which would prevent the further consideration of so-called "plastic design" procedures. Although at least one structure has been designed according to this procedure, general application of plastic theory should await the study of some further limitations, local instability of flange elements being one of the most critical

(VIII) ACKNOWLEDGMENTS

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(IX) References

Reports in Lehigh Series

1. Luxion, W. W., and Johnston, B. G., "Plastic Behavior of Wide Flange Beams," The

WELDING JOURNAL, **27** (11), Research Suppl., 538-s to 554-s (1948).

2. Beedle, L. S., Ready, J. A., and Johnston, B. G., "Tests of Columns Under Combined Thrusts and Moments," *Proc. Soc. Exptl. Stress Anal.*, **VIII,** No. 1, 109–132 (1950). WRC Bull. No. 8.

3. Yang, C. H., Beedle, L. S., and Johnston, B. G., "Plastic Design and the Deformation of Structures," Progress Report No. 3, THE WELDING JOURNAL, **30** (7), Research Suppl., 348-s to 356-s (1951).

4. Topractsoglou, A. A., Beedle, L. S., and Johnston, B. G., "Connections for Welded Continuous Portal Frames," Part I, *Ibid.*, **30** (7), Research Suppl., 359-s to 384-s (1951); Part II, *Ibid.*, **30** (8), Research Suppl., 397-s to 405-s (1951); Part III to be published.

Other References

5. Adams, C. A., and others, "The Weld Stress Problem," THE WELDING JOURNAL, **24** (6), 313-s to 318-s (1945).

6. American Welding Society, *Welding Handbook*, 3rd ed., 1950.

7. Amirikian, A., "Future Development in Welded Steel Buildings," THE WELDING JOURNAL, **27** (8), 593 (1948).

8. Baker, J. F., "A Review of Recent Investigations into the Behavior of Steel Frames in the Plastic Range," *Jnl. Inst. Civil Engrs.*, 185–240 (January 1949).

9. Cross, H., "The Relation of Analysis to Structural Design," Trans. A. S. C. E., **101**, 1363 (1936).

10. Donnell, L. H., "Plastic Flow as an Unstable Process," *Jnl. Applied Mechanics*, **9** (2) A-91 to A-96 (June 1942).

11. Greenberg, H. J., and Prager, W., "On Limit Design of Beams and Frames," Tech. Report No. 5, Brown University, October 1949.

12. Horne, M. R., "The Effect of Strain-Hardening on the Equilization of Moments in the Simple Plastic Theory," *Welding Research (Br.)* V5, N1, 147 (February 1951).

13. Kollbrunner, C. F., *Stability in the Elastic and Plastic Range of Plates Subjected to Compression (Report of Tests)*, Zurich, International Assn. for Bridge and Structural Engineering, vol. 3, p 222 (1935).

14. Nadai, A., *Plasticity*, McGraw-Hill Co., New York (1941).

15. Osgood, W. R., "Notes on Compression Testing of Metals and the Column-Strength Curve," Research Committee A (Mechanical Properties of Metals), Column Research Council, 1950.

16. Roderick, J. W., and Phillips, I. H., *Carrying Capacity of Simply Supported Mild Steel Beams, Engineering Structures*, Academic Press Inc., 9, New York (1950).

17. Timoshenko, S., *Strength of Materials*, vol. II, 2nd ed., D. Van Nostrand Co., Inc., New York (1941).

18. Van den Broek, *Elastic Energy Theory*, Wiley & Sons, New York (1946).

19. Van den Broek, J. F., Theory of Limit Design, John Wiley & Sons, Inc., New York (1948).

20. Wilson, W. M., and Hai, C. C., "Residual Stresses in Welded Structures," *Univ. Ill. Bull.*, **43**, No. 40 (February 1946).

21. Yang, C. H., "The Plastic Behavior of Continuous Beams," Ph D. Dissertation, Lehigh University, 1951.

22. Zehner, C., and Hollomon, J. H., "Deformation of Metals," *Jnl. Applied Physics*, **17**, No. 2, (February 1946).

(X) NOMENCLATURE

E = modulus of elasticity.
E_t = tangent modulus.
f = shape factor.
h = depth of section.
I = moment of inertia.
I_e = moment of inertia of the elastic part of a section.
I_p = moment of inertia of the plastic part of a section.
L = total length of a column or a beam.
M = moment.
M_p = full plastic moment, often termed "plastic hinge" moment.
M_y = moment at which flexural yield point is reached.
S = section modulus.
P = load on a column.
P_{cr} = critical load.
P_t = tangent modulus load.
t = thickness of the web of an I-section or a plate.
y = distance to the neutral axis.
Z = plastic modulus.
Z_p = plastic modulus of the plastic part of a section.
v = deflection of a beam.
W = concentrated load.
ϵ = strain.
σ = normal stress.
σ_r = residual stress function.
σ_{rt} = tensile residual stress.
σ_{rc} = compressive residual stress.
σ_y = lower yield point stress.
ϕ = rotation per unit length; curvature.

Appendices

APPENDIX A. COUPON TEST RESULTS

The mechanical properties of the material of the beams were determined by simple tension and compression tests to secure necessary data for theoretical computations. A constant strain rate of about 1 micro inch per inch per second was adopted for all tests. This rate was set in the elastic range, the valve setting being maintained constant throughout the test. Most tensile tests were carried into the strain-hardening range. Due to the difficulty of measuring the strain, compression tests were stopped before reaching the strain-hardening range. In all calculations the material is assumed to have identical stress strain properties in tension and compression. Two typical stress-strain curves plotted from test data are shown in Fig. 58. Idealized diagrams consisting of 3 straight lines in the elastic, plastic and strain-hardening regions were used in theoretical computations and were based upon average test data. The average results are given in Table 7.

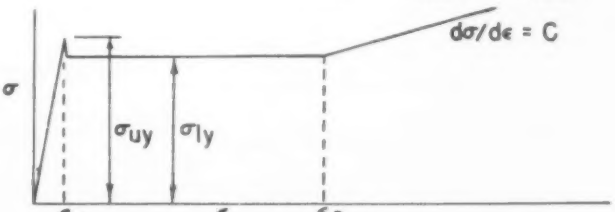
APPENDIX B. RESIDUAL STRESS IN A PLASTICALLY BENT BEAM

A short length of a beam is under a bending moment M_0, Fig. 59. In Fig. 59 (*b*) the yielded portion of the section is represented by the shaded area, and the stress distribution is shown in Fig. 59 (*c*).

When the moment on the section is removed a pattern of residual stress is left due to the plastic strain in the yielded zone. Assuming that the section behaves in elastic fashion under an unloading moment equal to M_0, the corresponding stress distribution will be linear as shown in Fig. 59 (*c*). The residual stress pattern is actually the shaded area between these two stress distributions as replotted diagrammatically in Fig. 59 (*d*). Van den Broek has demonstrated the above in his book *Elastic Energy Theory.*[18] The section will behave elastically when

Table 7—Summary of Coupon Test Results

Section and location of coupons	*Type of test*	*Upper yield point, σ_{uy}, ksi.*	*Lower yield point, σ_{ly}, ksi.*	*Elastic strain, ϵ_y, in./in.*	*Plastic strain, ϵ_s, in./in.*	*Strain hardening modulus C, ksi.*	*Ultimate strength, ksi.*
8WF40 flange (10 tests)	Tension	37.75	37.55	.....	.....	...	...
8WF40 web (5 tests)		39.76	39.52	.....	.....	...	...
8WF40 flange (6 tests)	Compression	37.63	37.35	.....	.....	...	...
8WF40 web (5 tests)		38.08	37.92	.....	.....	...	...
8WF40 flange (8 tests)	Tension	...	37.6	0.00124	0.0139	636	64.8
8WF40 web (3 tests)		...	38.5	0.00129	0.0141	644	66.2
14WF30 flange (8 tests)	Tension	...	38.2	0.00126	0.0161	599	62.2
14WF30 web (4 tests)		...	40.7	0.00137	0.0185	615	67.7



it is subsequently loaded so long as the maximum moment is less than M_0.

The stress pattern of Fig. 59 as well as the deflection of the beam during unloading can be derived neglecting the shear strain in the beam.

With the beam initially under the moment, M_0, suppose the moment on the beam is reduced to a value M such that M is smaller than M_0. From Fig. 60,

$$\frac{\epsilon_y}{y_0} = \frac{\epsilon}{y}$$

$$\epsilon = \frac{y}{y_0}\epsilon_y$$

where ϵ_y = strain corresponding to the stress σ_y. In Fig. 60 ϕ_0 is the unit angle change corresponding to moment M_0. Let ϵ' = permanent strain at any point in the plastic zone (the total strain is made up of the elastic strain ϵ_y and the permanent strain ϵ' (Fig. 61). Then from Fig. 60,

$$\epsilon' = \left(\frac{y}{y_0} - 1\right)\epsilon_y \qquad (10)$$

Now, under moment M, referring to Fig. 62

$$\phi = \frac{d^2v}{dx^2} = -\frac{\epsilon}{y}$$

where v equals the vertical deflection of the bending member under moment M. The value y_0 is a constant for a constant M_0. For y less than y_0 the region is elastic under the previous loads and the stress is dependent upon ϕ ($\sigma = Ey\phi$). However, for y greater than y_0, the stress distribution is modified by the prior plastic strain. For example the resultant stress distribution for a particular value of M is shown in Fig. 62.

The relationship between M and ϕ will now be developed, M being the total applied moment subsequent to a moment M_0. Let

σ_1 = stress at area above y_0.
σ_2 = stress at area below y_0.

Then

$$\sigma_1 = E(\epsilon - \epsilon').$$

$$\sigma_1 = -E\left[y\frac{d^2v}{dx^2} + \epsilon_y\left(\frac{y - y_0}{y_0}\right)\right] \qquad (11)$$

$$\sigma_2 = -Ey\frac{d^2v}{dx^2} \qquad (12)$$

In developing the following expressions for the magnitude of residual stress, only the positive side of the neutral axis is considered. This is the lower side according to the engineering convention. On the upper side, stresses will be reversed. Then

$$M = \int_{-h/2}^{h/2}\sigma_y dA = -\left[2E\int_{y_0}^{y_0} y^2\frac{d^2v}{dx^2}dA + 2E\int_{y_0}^{h/2} y^2\frac{d^2v}{dx^2}dA + 2E\epsilon_y\int_{y_0}^{h/2} y\left(\frac{y - y_0}{y_0}\right)dA\right]$$

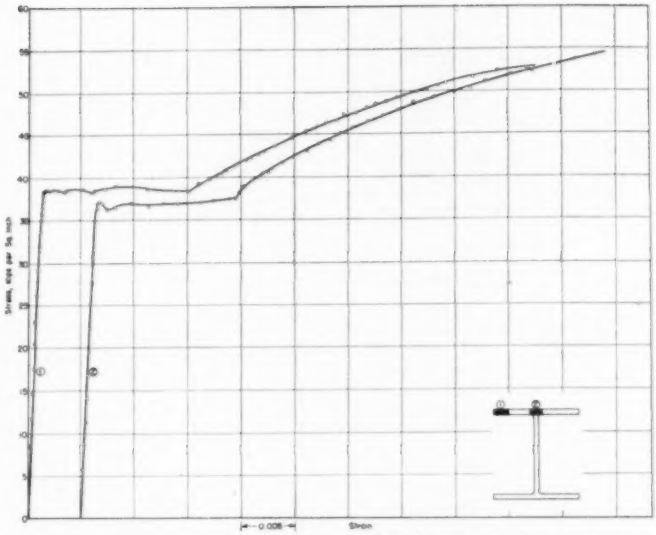


Fig. 58 Tension stress-strain curves for an 8WF40 beam (including strain-hardening range)

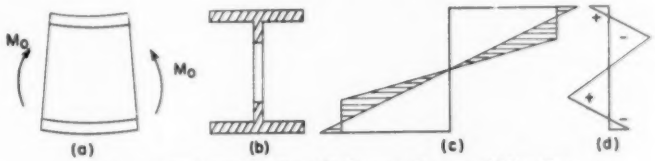


Fig. 59 Development of residual stress due to cold bending

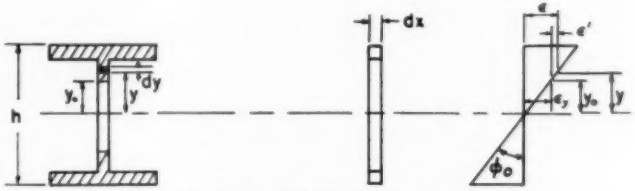


Fig. 60 Section yielded under moment M_0

Since $\frac{d^2v}{dx^2}$ does not depend on y,

$$M = -EI\frac{d^2v}{dx^2} - \sigma_y\frac{I_p}{y_0} + \sigma_y Z_p \qquad (13)$$

where the moment of inertia of the plastic portion is

$$I_p = 2\int_{y_0}^{h/2} y^2 dA,$$

the plastic modulus of the plastic portion is

$$Z_p = 2\int_{y_0}^{h/2} y dA,$$

and $\sigma_y = E\epsilon_y$. From Eq. (2),

$$\frac{d^2v}{dx^2} = -\left[\frac{M}{EI} + \frac{\sigma_y}{EI}\left(\frac{I_p}{y_0} - Z_p\right)\right] \qquad (14)$$

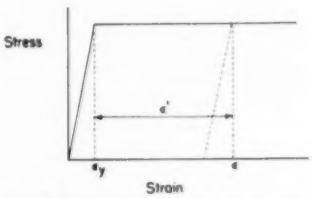


Fig. 61 Idealized stress-strain diagram

$$v = -\iint\left[\frac{M}{EI} + \frac{\sigma_y}{EI}\left(\frac{I_p}{y_0} - Z_p\right)\right]dxdx$$

When $M = 0$, i.e., the section is unloaded,

$$\left[\frac{d^2v}{dx^2}\right]_{M=0} = -\frac{\sigma_y}{EI}\left[\frac{I_p}{y_0} - Z_p\right] \qquad (15)$$

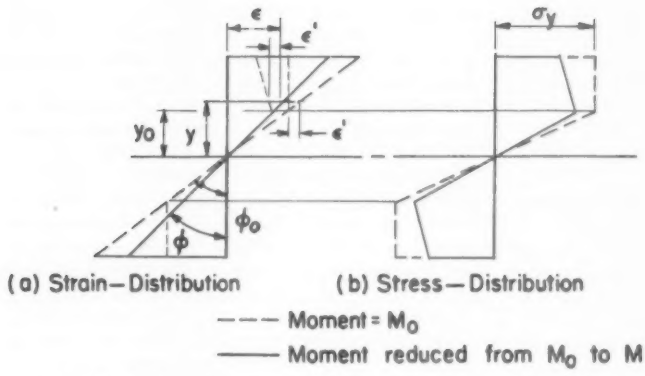


Fig. 62 Strain and stress distributions under moments M_0 and M

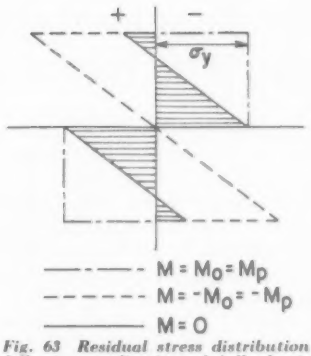


Fig. 63 Residual stress distribution following application of full plastic moment

The magnitude of residual stress remaining in the beam after plastic bending followed by complete removal of moment may be computed using Equations 11 and 12 for σ_1 and σ_2. Thus.

$$\sigma_{r1} = -E\left[y\left|\frac{d^2v}{dx^2}\right|_{M=0} + \epsilon_y\left(\frac{y-y_0}{y_0}\right)\right] \quad (16)$$

$$\sigma_{r2} = -Ey\left|\frac{d^2v}{dx^2}\right|_{M=0} \quad (17)$$

Substituting the value from Equations 15 into 16 and 17

$$\sigma_{r1} = \sigma_y\left[\frac{y}{I}\left(\frac{I_p}{y_0} - Z_p\right) - \left(\frac{y-y_0}{y_0}\right)\right] \quad (18)$$

and

$$\sigma_{r2} = \frac{\sigma_y y}{I}\left(\frac{I_p}{y_0} - Z_p\right) \quad (19)$$

When $y = y_0$, from Equation 19

$$\sigma_{r1} = \sigma_{r2} = \frac{y_0\sigma_y}{I}\left(\frac{I_p}{y_0} - Z_p\right) \quad (20)$$

When $y = h/2$ from Equation 18 and using $\epsilon_y = \frac{\sigma_y}{E}$

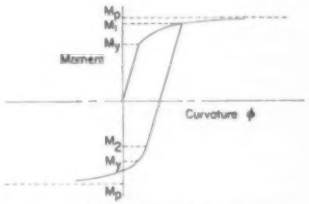


Fig. 64 M-ϕ relationship for a partially plastic member, unloaded, and reloaded in the opposite sense (diagrammatic)

$$\sigma_{r1} = \sigma_y\left[\frac{h}{2I}\left(\frac{I_p}{y_0} - Z_p\right) - \left(\frac{h-2y_0}{2y_0}\right)\right] \quad (21)$$

When the moment M_0 is equal to the plastic hinge moment, M_p, then y_0 approaches zero (Fig. 6). From Equation 6,

$$\sigma_{r2} = \sigma_y \quad (22)$$

At the extreme fiber when $y_0 \to 0$ and $y = h/2$, from expression (21)

$$\left|\sigma_{r1}\right|_{\substack{y_0 \to 0 \\ y = h/2}} = -\sigma_y\left(\frac{Z}{S} - 1\right)$$

and since the shape factor is defined by $= Z/S$. Then

$$\left|\sigma_{r1}\right|_{\substack{y_0 \to 0 \\ y = h/2}} = -\sigma_y(f-1) \quad (23)$$

which gives a compressive stress on the lower fiber and a tensile stress on the upper fiber. Such a distribution for the condition that $M_0 = M_p$ has been shown in Fig. 241 of Reference 17 and is also shown in Fig. 63. It may be obtained by use of Equations 22 and 23 which give the maximum possible residual stresses at the two points.

The general expression (14) holds when a moment in the opposite sense is applied and until the yield condition is reached. Referring to Fig. 64 these expressions would apply until the reversed moment reached the value M_2, the magnitude of which depends theoretically upon the magnitude of M_1. (The Bauschinger effect is ignored, but this would lower M_2 still further.)

The Micro-Mechanism of Fracture in the Tension Impact Test

Discussion by Glenn W. Geil

Professor Bruckner's tests on ingot iron are of special interest to me. Does the author have any explanation as to why peaks at 127° F. in the impact-temperature curves for ingot iron should be present for the tests made with initial energies of 220 and 110 ft.-lb. and not be present in the tests made with initial energy of 45 ft.-lb.? Perhaps additional tests at 127° F. with the high initial energies might indicate a scatter in energy values similar to that reported for the tests made with an initial energy of 45 ft.-lb. Does the author believe that these peaks are really significant?

Professor Bruckner reports that his metallographic examination revealed a maximum population of mechanical twins in the specimen corresponding to the peak energy absorption in the tests made with initial energy of 110 ft.-lb., thus establishing that maximum twin density and peak energy absorption were coincident. Did the author make a metallographic examination of the specimens of this series that were fractured at temperatures below the transition range? If so, was the extent of mechanical twinning in these specimens greater or less than that observed in the specimen corresponding to the peak in the impact temperature curve at the high temperature end of the transition range? In some work, reported recently (Research Paper 2119, *Jnl. Research*, NBS, Vol. 45 (1950)), in which a preliminary study was made of the mechanical twinning in ingot iron specimens slowly extended in tension at temperatures ranging from −196 to +100° C., a maximum twin density was observed in the specimens fractured at the lowest temperature (−196° C.). At this temperature the energy absorbed and the ductility of the specimen also were least and thus the data apparently indicate a coincidence of maximum twin population and minimum energy absorption.

Author's Closure

In answer to the written discussion by Dr. G. W. Geil it should first be noted that the results of his tests to which he refers were obtained for ingot iron specimens slowly extended in tension, whereas, the author's data were obtained from tension impact specimens provided with a notch. Geil's tests were therefore made under conditions of maximum possible uniformity of strain in the volume of the tensile specimen whereas the notched tension impact tests provided a volume of metal in and close to the notch with a definite strain gradient.

The first question which Geil asks refers to the peaks obtained in the tension impact data for Armco iron fractured with 220 and 110 ft.-lb. of initial energy in the pendulum. These peaks did not appear where the initial energy was reduced to 45 ft.-lb. and Geil therefore suggests that if more tests had been made at the higher initial energies a scatter of data rather than a peak would have been obtained.

The author believes that the peaks in the impact data for the higher initial energies are significant but only for the particular geometry of specimens and test conditions employed. The peaks were never encountered before in any of the tests made with other ferrous materials. The main responsibility for the odd shape of the impact temperature curves would therefore be that of the material itself, Armco iron in its response to the stress system which the specimen geometry and initial energy employed produce.

An attempt was made by the author to explain the occurrence of the peaks under the heading "Discussion of the Data on Armco Iron" on page 464-s of the paper published in THE WELDING JOURNAL for September 1951. Some additional statements may help to clarify this portion of the paper, viz., Fig. 14 gives the hardness values along the longitudinal center-line of the three specimens examined and clearly indicates that maximum hardness of the center of the notch volume decreased with test temperature. A reasonable assumption was that other portions of the notch volume than the central region had contributed to the anomalous, extra energy absorption represented by the impact peak. This was found to be the case when more extensive hardness surveys were made of the entire notch area on the plane of polish. The specimen representing the impact peak had peak hardness in a tubular region under the notch. This portion of the specimen was then visualized as having been strained to a greater extent than the specimen tested at higher temperature above the peak due to a change in the stress system occasioned by the early fracture of the central region as shown in Fig. 14. The central region of the specimen tested above peak temperature fractured at a later stage as shown by the higher maximum hardness in Fig. 14, thus making it possible to maintain the transverse stress gradient and shear restraint which limited the level of strain in other portions of the notch volume.

It will be noted from Fig. 3 of the paper that the higher initial energy of 220 ft.-lb. gave a sharper indication of a peak than did the tests at 110 ft.-lb. Furthermore the individual values for the duplicate tests made at each temperature at the higher initial energies check each other closely. The author therefore believes that the peak is a real phenomenon which becomes less prominent as the strain rate and available elastic energy are reduced by decreasing the initial energy of test. The exact mechanism which produces the peak cannot be stated at present but some tests are underway in the laboratory of Professor C. E. Taylor, T.A.M. Department of the University of Illinois, to determine the strain distribution. Professor Taylor is using a plastic replica of the notched tension impact specimen about

Glenn W. Geil, Metallurgist, National Bureau of Standards.

Paper by Walter H. Bruckner was published in THE WELDING JOURNAL, 30 (9), Research Suppl., 459-s to 469-s (1951).

four times the size and will study the strain distribution in and near the notch volume using polarized light.

Another of Dr. Geil's questions concerns the evidence obtained with respect to the incidence of mechanical twins in the notch volume. This is stated in the third paragraph on page 464-s of the original paper as being 70, 1700 and 110 twins on the polished surface at the center plane of the notch volume, respectively, for the specimens above, at and below the peak impact energy obtained at 127° F. At test temperatures above 155° F. the number of twins decreased and at test temperatures below 115° F. the number of twins increased as judged by inspection rather than actual count as for the above three specimens. Because the peak energy specimen contained the largest number of twins we were concerned about the possibility that they had contributed to the energy absorption. The microhardness and X-ray diffraction studies reported in the paper show that the twins contributed a negligible amount of permanent strain. It should also be emphasized that the region of maximum density of twins did *not* occur in the same region of the notch volume having maximum permanent strain; thus, even though the peak energy and maximum twin density were coincident in the same specimen, they are apparently not related to each other or at least their relationship, if any, is unknown, at present. Also the reason for the occurrence of the very large twin density in the peak impact specimen is unknown. However, since the paper was written a recrystallization technique has been employed to show that tiny recrystallized grains grew at the intersection where two twins crossed, where a twin was stopped at some internal barrier and at the start of a cleavage crack apparently started by a twin. This evidence of transfer of elastic energy required for twin propagation into slip and cleavage is regarded as the final proof of the stated interrelationship of twinning and cleavage.

The author appreciates the opportunity to emphasize certain points and to present additional data which was afforded by Dr. Geil's discussion. He also thanks the many individuals who expressed an enthusiastic, high regard for the value of the paper as a contribution to the brittle fracture problem. Finally the author thanks the board for the Lincoln Gold Medal Award for 1951 and its chairman, Clarence E. Jackson, for considering the author's 1950 paper as worthy of this award.

Weldable Low-Alloy Steels for Pressure Vessels

by Franz Nehl

BECAUSE the equipment for producing rolled high-pressure drums in Germany has been destroyed or dismantled, welding is the only practical method of fabrication. With the weldable boiler steels hitherto available, the existing presses and bending rolls were too small to handle the wall thicknesses required for large drums operating below 750° F. but at pressures over 1400 psi. Consequently, it became necessary to develop weldable steels with such high yield strength at elevated temperature that all present pressure requirements can be met with thicknesses not over 3½ in. The high yield strength cannot be attained by quenching, which is not recommended for welded drums. The required yield strength must be attainable by simple heat treatments, the cooling rate during which must not exceed 12 to 27° F. per minute for heavy drums. Owing to formation of martensite during welding, the air-hardening Cr-Mo and Cr-Mo-Ni steels cannot be considered. The formation of martensite creates microstructural stresses leading to cracks.

Within the limits of present specifications it is known that in order to keep the thickness of the largest desired drums to a maximum of 3½ in., the yield strength at 660° F. must be at least 50,000 psi. The steels often used for drums in USA and Germany contain 0.15–0.20% C, 0.30–0.40% Si, and about 1% Mn, and have a yield strength of 30,000 psi. at 660° F. Only recently have steels become available with 0.18% C, 1% Mn, 0.9% Cr and 0.25% Mo, with a yield of 35,500 psi. at 660° F.

Even before the war welded drums were made of copper-nickel steels[1] which not only had high yield strength at elevated temperatures, but were superior to manganese and chromium-manganese steels in sensitivity to weld cracking. The high yield strength of the copper-nickel steels was obtained by a precipitation hardening treatment which is largely independent of the cooling rate. It was found[2] that a small addition of molybdenum which did not affect weldability improved these steels, so that a steel containing 0.15–0.20% C, 1% Cu, 0.8% Mn, 0.2% Mo, and 0.8% Ni had a yield strength of 35,500–43,000 psi. at 660° F. The surprising discovery was made that the yield strength of

Abstract of "Schweissbare niedriglegierte Stähle mit hoher Warmstreckgrenze für Hochdruck-Kesseltrommeln," published in *Stahl und Eisen*, **71**, 1443–1444 (1951). (Abstracted by Dr. G. E. Claussen.)

Table 1—Composition of the Copper-Nickel-Molybdenum Steels

	C, %	Si, %	Mn, %	Cr, %	Cu, %	Mo, %	Ni, %	Ta + Cb, %
Steel A	0.14	0.35	1.0	0.10	0.85	0.24	0.74	..
Steel B	0.15	0.43	0.96	0.30	0.98	0.22	0.79	0.013

these Cu-Ni-Mo steels could be raised considerably without affecting weldability by adding traces of certain carbide-forming alloying elements.[3] The carbides precipitate even during very slow cooling after normalizing, the tensile strength rising to over 114,000 psi. and the yield strength being over 57,000 psi. at 660° F. In this condition the steel has no more tendency toward hardening and cracking during welding than a boiler plate of 63,000–75,000 psi. tensile strength. No martensite is formed in the heat-affected zone and consequently microstructural stresses are low. Since the products of transformation in the steel form at a much higher temperature than martensite, shrinkage stresses are low. In other words, the weldability of a steel depends, not so much on its tensile strength as on the effect of the alloying elements on the structure after transformation.

Owing to the high tensile strength (over 114,000 psi.) of normalized, welded drums of this steel, they must be reheated to 1110-1200° F. before being placed in service. During this treatment the transformation products are decomposed, the tensile strength is lowered, but the yield strength at elevated temperature is decreased only slightly. As a result a yield ratio (yield strength at 660° F./tensile strength at room temperature) of over 60% is achieved, compared with 38% for plain carbon steel and 45% for medium manganese steels. The unusual properties at elevated temperatures are connected with the precipitation of very fine copper and carbide particles during the treatment at 1110-1200° F. The composition of the steels that were studied is given in Table 1. The results are averages of several specimens. The somewhat higher chromium content of Steel B is due to the fact that the tantalum and columbium are derived from scrap austenitic stainless steel. Tests after 10,000 hr. under load showed neither a decrease of yield strength at elevated temperature nor a rise in tensile strength. The reduction in toughness due to blue brittleness at 660° F. was no greater than is found in other steels.

A number of high-pressure drums have been made of the Cu-Ni-Mo steels. The welds were made in two layers with a twin head using submerged arc welding with a wire of copper-nickel-molybdenum steel containing columbium. The twin head was used to avoid cracks. The filler wires were $6^3/_4$ inches apart. To weld $3^1/_4$ ft. of joint inside and outside required only about seven minutes.

The present results show that this steel can be used in heavy thicknesses without distortion and hardening cracks. The strength attained by this air-cooled steel could be obtained in previous steels of this alloy level only by oil or water quenching.

References

1. Nehl, F., *Elektroschweissung*, 7, 81–86 (1936).
2. Nehl, F., *Mitt. Ver. Grosskesselbesitzer*, No. 73, 186–196 (1939).
3. Nehl, F., *Ibid.*, No. 12/13, 228–237 (1951).

Table 2— Properties at 68 and 660° F. of the Steels in Table 1

Temperature of test, °F.	Steel	Normalizing temperature	Reheating temperature	Yield point, psi.	Tensile strength, psi.	Ratio of yield point at test temperature to tensile strength at 68° F., %	Elongation % in 5 diameters	Reduction of area
68	A	880	..	60,500	90,000	68	25.5	68
"	B	"	..	74,000	128,000	57	11.3	20
"	A	"	1155	56,500	79,000	72	25.0	65
"	B	"	1155	75,000	96,000	78	20.6	59
660	A	"	..	43,000	91,000	47	24.5	47
"	B	"	..	69,000	126,000	54	15.0	26
"	A	"	1155	43,000	78,000	55	25.2	55
"	B	"	1155	65,000	91,000	67	20.3	48

Cooling rate during normalizing = 12° F. per minute.
Time of reheating treatment = 8 hr.

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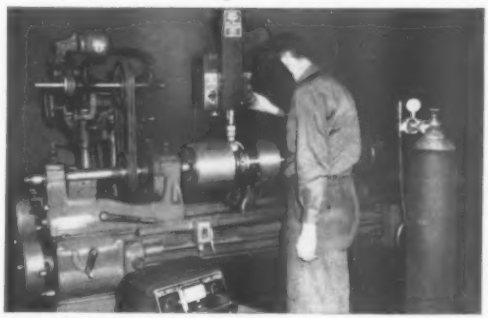

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